GENERAL ELECTRIC REVIEW

A MONTHLY MAGAZINE FOR ENGINEERS

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A Street Lighting Installation of the Modern Type Reduces Accidents and Crimes at Night, and Both Day and Night is a Subject of Civic Pride

The above photograph, taken in Stamford, Conn., is an example of the effective result produced by street lighting specialists. One of the principal contributing factors is the glassware which has been developed for this purpose, and which is described on page 304.

GENERAL ELECTRIC REVIEW

RAILWAYS

It is of considerable interest to note that the Stockton and Darlington Railway, the first railroad in the world to be opened for the public conveyance of passengers and freight, began its career only 99 years ago. Every school boy knows that George Stevenson's locomotive hauled the coaches successfully on the great opening day in 1825. But it is not such common knowledge that it was only the courage and backbone of Stevenson that prevented this historic road being operated by the "more economical" method of horse traction. The learned directors were convinced that horse traction was more economical and it is somewhat astonishing to learn that much of the "goods traffic" was handled during 1825 and later by horses! Such is the history of invention.

We have these thoughts in mind on reading an article that we publish in this issue, written by Mr. A. H. Armstrong. He points out that one of our most perplexing problems is to find a means of improving the credit of our railways so that they may attract the investment of the large amounts of capital needed annually for roads and equipment and to meet maturing securities. This condition of affairs is just as astonishing as it is true. But there is a perfectly definite reason for it—the management of our railways became unpopular in the public eye and this led to restrictive legislation in a multitude of directions. Restrictions have been added to restrictions until today Mr. Armstrong says, "98 per cent of the new money put into our railroads has come from borrowing at rates above the return that was earned." This condition cannot continue without heading for disaster.

We do not argue that the railways were in all cases blameless of abuse, but we do say frankly that we have more tolerance towards the sins, or imagined sins, of pioneers who add untold wealth to their nation than we have sympathy for would be reformers, who shoulder no responsibilities and stir up public sentiment to a point where the usefulness of one of the greatest economic assets of the nation is jeopardized.

We often feel that the public do not know or appreciate what our railroads have done for us. The development of the United States of America during the last century is one of the wonders of the world. Its development is so prodigiously large that it is non-understandable. Every American who is proud of his country and her development should know and always remember the fact that the rate of America's progress is just the same as that of her railway construction.

In the year 1830 there were just 23 miles of railroad in operation in the entire United States. Ten years later, in 1840, there were 2818 miles in operation. There is a book full of history in these two figures but it is too long to write. It is the history of America's development for one decade, a decade in which she started her great triumphal march toward world leadership in commerce.

For those who like history in tabloid form and who have the imagination to fill in between the lines, here is some more—In 1850 there were 9021 miles of railroad in operation; in 1860, 30,626 miles; in 1870, 52,922 miles; in 1880, 93,262 miles; in 1890, 166,654 miles; in 1900, 194,321 miles; in 1910, 240,439 miles; and in 1920, 260,000 miles.

The railways of England and Europe were built to supply a more efficient means of transportation than that already in use. But the railways of America were built to open up her undeveloped natural resources and to aid the settlement of territory that was either entirely unsettled or only sparsely populated.

It was the courage of our pioneers that accomplished these miracles and built up an empire in desert places and on wild prairie lands. The untold mineral resources of America and the hundreds upon hundreds of thousands of square miles of fertile land have only become useful to man, and available to every section of the country, through the efforts of those great nation builders who bridged our rivers and conquered our mighty mountain ranges with their double bands of steel and iron horses. These men were in truth the fathers of their country. It was the very marrow of their backbones that cemented the United States from the shores of the Atlantic to the Pacific into a national and industrial whole.

Does the man in the street, and especially does the farmer, realize what the value of his land, his products and his labor would be without our railroads?

But neither praising our pioneers nor regretting the restrictions placed on our railroads will hinder that downward tendency in the return on railway investments which became manifest in about the year 1906 and has become more apparent and disconcerting each succeeding year.

The general policy of American railways to pay only a part of their surplus earnings in dividends and to put a liberal share of earnings back into the property cannot be continued when earnings are so sadly reduced.

It is a generally accepted fact that the volume of freight traffic on American railways doubles each 12 years and that the number of passenger miles doubles every 15 years. How can this future need be provided for in face of the fact that during 1915 about one-sixth of the entire mileage of the country was in the hands of receivers?

When we add to these disheartening facts the increased cost of construction, the heavier equipment and rails needed to meet modern traffic conditions and the increased cost of labor the future indeed looks dark.

There must be a solution to this perplexing problem—the prosperity of the country depends upon it. We believe that it is in the province of the engineer to find a solution and not only in his province but in his power.

In 1825 there were those in excellent position to know the facts who maintained that horse traction was more economical than steam traction. In 1924 after 99 years of steam traction what do we think—what do we know? The face of the world and the course of our civilization has been changed by the courage of our 1825 pioneers.

The electric locomotive is more fully developed in 1924 than the steam locomotive was in 1825 and its capabilities are better known. Some of us feel that we know the future of the electric locomotive but there are many in an excellent position to know who maintain that steam traction is more economical than electric traction. What will people be saying in the year 2024?

There is no longer even a shadow of a technical question left. Electric locomotives and multiple unit cars can handle any traction problem in the country. Dollars and cents are the only argument.

The electric motor has won in every field it has invaded—but the victory has not always been with the first installations. But in the case of the electric motor in railway work no apology of any kind is needed. The horse-drawn car is gone. Electric locomotives haul our heaviest freight trains over our most severe mountain grades. Terminal electrifications have added millions to city land values in addition to giving ideal traction facilities.

When our hydro-electric resources are more fully developed and cheaper electric power is available without the railway companies having to shoulder this heavy burden for each new undertaking and when standardization has eliminated the heavy development charges against each new proposition, we hope that the economies of electric traction will be more generally recognized.

We have yet to see the fully electrified railroad where the new power is used for traction purposes and in every other department such as is involved in the construction, operation and maintenance of the railroad in its entirety. When this day arrives there are innumerable economies to be secured and many uneconomical practices which have been in vogue for the last half century of steam operation will be replaced by newer and more economical methods alone made possible by the elasticity of power supplied from a central source.

Mr. Armstrong says "that if all our railways were electrified the annual saving in coal would amount to 100,000,000 tons." This figure alone is of such national importance that it is hard to overestimate the benefit to future generations.

J. R. H.

Our Railroads

By A. H. Armstrong

Assistant Engineer, Railway Department, General Electric Company

After pointing out how seriously our transportation system is handicapped at present in being unable to obtain an adequate supply of capital on reasonable terms, the author deals with the many advantages of electric traction. He divides his subject under the following headings: terminals and tunnels; mountain grades; fuel or electric power; locomotive maintenance and cost of electrification. As is common in our other modern economic problems it is the work of the engineer to find the solution. This address was delivered before the St. Louis Railway Club and the A. I. E. E. at St. Louis on March 14, 1924.—Editor.

Perhaps one of the most perplexing questions facing us today is the problem of improving the credit of our railroads, so that they may attract the investment of the large sums needed annually for road and equipment and to meet the requirements of maturing securities. It is estimated that additions to capital totalling approximately $800,000,000 for road and equipment alone will be required to meet traffic growth per year. During the past few years over 98 per cent of the new money put into our railroads has come from borrowing at rates above the return that was earned. No industry can continue doing business for long on such terms. Not only should the effectiveness of additions to capital account be measured by the increased traffic handled, but also by at least a corresponding increase in net operating revenue as well.

In this connection, the statements of President Rea of the Pennsylvania System recently made before the United States Chamber of Commerce at Philadelphia are quoted:

> "In the year 1917, the year we entered the World War, the net operating revenue of all class I railroads was $934,000,000. For the year 1923 * * * it will probably be in the neighborhood of $970,000,000. In the meantime the huge sum of three and a quarter billions of dollars has been expended upon the railroads for additions to road and equipment. It will, therefore, be seen that the investment of that immense sum has brought practically no increase in net operating revenues, even in a year during which railroad traffic broke all previous records."

It is not the purpose of this address to discuss the injustice or fairness of the several legislative acts which control, to a large extent, the operation of our railroads, or whether labor receives too large or too small a percentage of the income earned by the roads with the rates they are permitted to charge. The point of the matter is that if present conditions are to hold in the future, and further wage increases recently granted indicate no promise of relief in this direction, we are confronted with the discouraging fact that new capital cannot be invested in railroad securities with much expectation of earning an adequate return, and in addition there are many who think that present freight rates are now too high and should be materially reduced. How then can we hope to accomplish the apparently impossible task of satisfying the demands of shipper, labor and investor, keep the transportation machine in efficient working order and provide adequately for future traffic growth?

If I were to answer such a question it would be to say "Look to the Engineer." His invention of the steam engine made the railroad possible and his achievements during the 100 years of subsequent development have kept pace with the increasing demands made upon him. Heavier and improved rails have replaced light ones, steel structures have superseded wood, relocation of track has reduced ruling gradients and corrected alignment so that vastly improved steam engines can haul heavier trains at higher speeds with greater economy and safety.

The great American transportation system, of which we are so justly proud, is a testimonial to the effective co-operation of engineer and operator working together in full appreciation of their mutual dependency. The fruits of invention of the one have been promptly exploited by the other with the result of vastly increasing the effectiveness of man labor. More than three thousand horsepower is now under the control of one operator, fuel efficiency of nearly two pounds of coal per horsepower hour has been reached, road bed and structures are equal to the needs of the heavy trains hauled on them and the morale of the railroad organization has approached its pre-war standards. Yet three and one quarter billions of dollars have been expended upon our railroads in six years without effecting any material increase in net operating revenues.

It would appear as if the engineer had no further improvements to offer and the railroad problem must be left to some other solution were it not for the knowledge that the huge sums spent from 1917 to 1923 were almost entirely for steam equipment and facilities, and there is a new type of motive power that has demonstrated its peculiar fitness for railroad service. I refer to the electric motor which has so completely revolutionized other industries and offers very attractive advantages that hold promise of greatly improving our railroads. The modern steam engine is the result of 100 years development and it is a most marvelous machine to which mankind owes much. Its performance and limitations are both faithfully reflected in railroad transportation today. Train weights, operation, schedules, capital expenditures, revenues, all are dependent upon what the steam engine can do. The railroad operator and financier think in terms of steam engine performance and the whole railroad structure, physical and administrative, is founded upon the well understood operation and restrictions of the steam engine.

It is not that the steam engine has failed, but there are limits to its adaptability to meet all the new traffic conditions that arise in our national development. For example, the tremendous congestion of population in our cities has created the imperative need for rapid transit over wide areas and with frequent stops. The multiple unit electric train has successfully met the requirements of this service for which the steam engine is not fitted. The heaviest freight and passenger trains are now being comfortably hauled through tunnels previously made unsafe by the smoke and gases of the steam engine which had to be retired from such tracks. Apparently rapid transit local trains and tunnel approaches for all trains are becoming inseparable to modern railroad terminals in our larger cities and electricity is being regarded as the superior power for train haulage under such conditions.

Electric locomotives are hauling heavy trains, passenger and freight, over mountain divisions where grade and traffic conditions are so severe that the steam engine fails to fully meet the service requirements. In fact it is instructive to note in practically every instance of electricity replacing steam, the controlling reason has been that the electric motor can do something not possible to accomplish by the steam engine, and it is in this spirit of greater achievement that the electrical engineer approaches the tremendous problem of helping to better the country's transportation system.

Not always is electrification adopted for the same reasons and some of its many advantages are outlined in the following brief summary:

1. Terminals and Tunnels

Freedom from smoke and gases makes the electric motor ideal for tunnels and city terminals. In some instances when such reason for adoption controlled, it was found expedient to extend electrification to include the suburban zone around cities and provide the better, cleaner and more reliable service which the rapid acceleration of multiple unit trains offers. Such installations have been uniformly successful and efficient and have made possible such terminals as the Pennsylvania and New York Central located in the center of New York's business and best residential districts. The lessons taught by these great passenger terminals might well be applied to the creation of freight centers built along the same lines of several platform levels made possible by the smokeless electric motor. Truck competition, so serious in short haul traffic, might become less a menace if railroad terminals could be more centrally located and provide better facilities for transfer of freight. Electricity may be properly looked to as a means of introducing much needed improvements in this direction.

2. Mountain Grades

It should always be kept in mind that the only economic function of a locomotive of any kind is to haul trains reliably and efficiently under all of the physical and climatic conditions that may arise. In this respect the steam engine is seriously handicapped by the necessity of providing for a complete fuel burning plant in its fire box and boiler which puts definite limits upon its construction and performance. Apparently these limits have been nearly reached in the modern steam engine and it is becoming very difficult to still further increase its output in answer to the always urgent demands of the operating department of our railroads for more power. Such further improvements as can be made in steam engine construction may be purchased at too great a sacrifice in reliability and cost of maintaining a machine that is becoming increasingly complicated. The electric locomotive, free from boiler restrictions and drawing unlimited power from huge electric generating stations, may be designed strictly as a hauling machine with free choice of axle weights, driving wheel base, tractive power, speed, in fact all of the essential characteristics that contribute to the success of a perfect traction engine. In the electric locomotive, therefore, the engineer is able to present to the railroad operator a fully developed machine that has demonstrated it is capable of successfully performing any service now being accomplished by the steam engine and also is free from some of the limitations of the latter which many think are seriously restricting the free development of railroading in this country today.

For example, mountain grade divisions constitute a serious physical and economic problem in steam engine operation. The Chicago, Milwaukee and St. Paul officials will tell you that electric locomotives have practically eliminated the ruling grades of the four mountain ranges in their 700 miles of electrified track, and trains are delivered on time with a certainty impossible of attainment with the steam engines replaced. This success is due to greater tractive effort, higher speed, electric braking on down grades, 440 miles continuous train run without change, 6000 miles continuous locomotive runs between inspections and minor repairs, and finally by establishing a new high standard of reliability as shown by the total repairs of 18 cents per mile run for an electric locomotive weighing nearly 300 tons.

These constitute strong arguments to the railroad operator intent upon widening the neck of the bottle to which mountain divisions may be likened in restricting the free movement of trains over a trans-continental road. Especially does electrification of congested single track mountain divisions in many instances offer a more attractive investment than double tracking or grade revision with continued steam operation.

3. Fuel or Electric Power

It is instructive to observe the new note of fuel economy appearing in increasing intensity in the design of later steam engines. Superheaters, feed water heaters and mechanical stokers are now accepted additions to modern steam engines carrying also greatly improved fire box and boiler construction.

The narrow spread now existing between fixed wages and rates which the railroad may charge is so small that economies of all kinds have assumed a far greater importance than in the days of the simple unadorned consolidation engines of only a few years ago. Material additions to capital account are now looked upon as wise and necessary expenditures, if accompanied by assurance of a reasonable reduction in the fuel bill. Some very vital figures are available bearing upon this matter of fuel now burned on our steam railroads. Not only are the railroads the largest consumers of coal of any national industry, but they are the biggest shippers as well. Over a quarter of all the coal mined is burned on the railroads, and its shipment in cars and engine tenders equals nearly one-fifth of all the revenue tonnage hauled over the country's 350,000 miles of track. These are astonishing figures and engine fuel certainly offers a fruitful field for effecting possible economy.

There is just one commodity that has not increased in price during these past abnormal years, and that is electricity. The engineer can claim much of the credit for this achievement as it has resulted in large part from his inventions in the equipment for generation and transmission of electric power. Nor is his labor along these lines yet nearly complete, if Emmet, for example, is able to bring about the general adoption of the mercury boiler and turbine with its demonstrated wonderful economy in fuel consumption. What the engineer has accomplished in making his contribution to the great electrical utility companies he can do in kind for the railroads. In fact, without going beyond the records of performance already established in electric power generation, distribution and utilization in electric locomotives, we are forced to accept the approximate truth of the astounding statement that 100,000,000 tons annually, or two thirds of the coal now burned on our railroads, can be saved as the result of complete electrification of all the roads in this country. Whatever improvements the future may hold in steam engine fuel economy, its very nature of a small portable individually operated power plant will leave it well behind in a competitive race with huge interconnected electric super-power systems, which are becoming more and more available as a universal source of cheap reliable power.

4. Locomotive Maintenance

The science of building, operating and caring for electric motors is so well known that comment is unnecessary except to say that little of the reliability and long useful life inherent to properly designed motors is lost by their adaptation to axle drive. Adequate factors of safety can be incorporated in electric locomotive construction to insure a low cost of upkeep. From operating records available, it may be accepted as a reasonable expectation that an electric locomotive can be maintained for eight cents per mile run for every 100 tons on drivers. Operating figures of steam engines of the Mikado and Mallet type are fully three to four times as great. Material reduction in the large item of steam engine upkeep may be expected therefore with the introduction of the electric locomotive.

5. *Cost of Electrification*

It will cost a great deal of money to replace steam engines with electric locomotives. It is always expensive to upset any established order of things. Much of the present steam engine facilities must be scrapped as of no value to electric operation. Coal and water stations, turntables, ash pits, roundhouses, much of the surplus shop equipment, at least every alternate division point with its accompanying yard classification tracks, all must be crossed off the books as unnecessary on electrified tracks. If the picture were reversed and all the roads were electrically operated, what chance would the steam engine advocate have of putting over a plan for introducing steam engines of even modern design and requiring the above imposing list of what would be new auxiliary equipment for their operation?

There are two outstanding fundamental factors persistently working for electrification that in the end must receive recognition as they become more fully appreciated.

First, the electric locomotive can carry railroading a peg higher in its full development because it can perform a service beyond the possibilities of the steam engine.

Second, it can effect operating economies over steam operation that are in many instances sufficient to pay a reasonably attractive return upon the new capital charges incurred. Broadly speaking, the ton-mile movement over our railroads doubles every twelve to fifteen years and absorbs new capital every year for road and equipment running into the hundreds of millions. If this huge expenditure is to be continued for steam equipment in the future as in the past, we can predict with certainty there is little hope of reducing the cost of hauling a revenue ton one mile. Electrification, however, holds out such expectation of reducing operating expenses without change in existing labor rates or working conditions.

The cost of electricity as offered by our large utility companies has not been kept level or cheapened by legislation, but by taking prompt advantage of every improvement in equipment which the engineer's inventiveness has made available, and these companies financed by private capital are in a most sound and healthy condition. The railroads can well take a leaf out of the same book and also profit to an unexplored extent by the gradual adoption of electricity and the electric motor as the modern equipment best suited to large city terminal and mountain division with further extensions as the future may more clearly determine.

Transcontinental Passenger Train "Olympian" Descending the East Slope of the Rockies

Removable Truck Type Panels

By H. E. Starbuck

Switchboard Sales Department, General Electric Company

As the removable truck type panel has found such an extensive field of usefulness during its very short life, the description given by the author of this important equipment should be of use to all of those who are interested in the construction and operation of power houses.—Editor.

In the smaller power stations in such industries as mills, smelters and refineries, and in many small factory power houses, the problem of station attendants has long been a serious one. Thoroughly trained operators are scarce and supply and demand enters into the problem in equal, or even greater, proportions to the question of dollars and cents.

In view of these conditions, the first installations of truck type switchboard panels were made in the smaller industrial power houses, but during the last few years the large central station has been adopting the replaceable unit idea on an ever increasing scale.

The truck type panel is removable and replaceable, either singly or in groups, and provides the best known method of restoring service without duplication of equipment after a breakdown no matter whether the breakdown is small or of serious proportions.

To a certain degree, the truck type panel switchboard is elastic. It can be added to, altered, or taken away from. And in general, its removal from one location to another presents no difficult undertaking.

Truck type panels have been standardized in the following capacities, although panels for ampere capacities exceeding those given are made.

Volts	Amperes	Phase
600	400 to 2000 inc.	2 and 3
4,500	400 to 2000 inc.	2 and 3
7,500	400 to 1200 inc.	2 and 3
15,000	400 to 1200 inc.	3

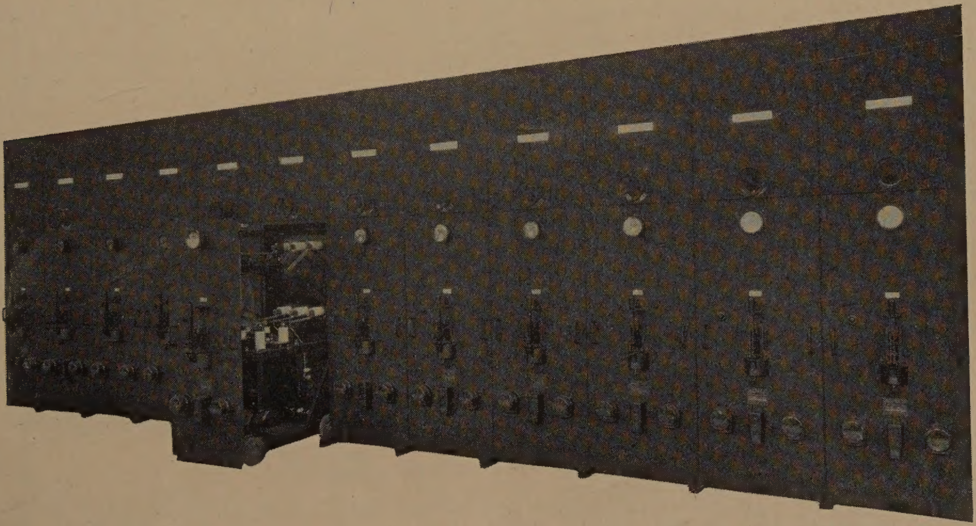

Fig. 1. Twelve-panel Switchboard Made Up of Safety Enclosed Removable Truck Type Panels

All panels for use with voltages up to 7500 are 76 inches high and vary in width from 24 inches to 36 inches. From 7501 to 15,000 volts, the panels are 100 inches high, which includes a 24-inch superstructure above a 76-inch panel. The width varies from 32 to 36 inches. The depth of all panels is 66 inches which allows them to line up, front and rear, regardless of voltage or capacity.

Up to and including 7500 volts, the buses are mounted in the rear of the housings. For 15,000 volts they are mounted in the superstructure. A superstructure 43 inches high provides a location for an auxiliary bus and selector disconnecting switches if two sets of buses are required.

Housings are designed either for mounting against the wall or at some distance from it, leaving an aisle at the back. In the latter case, a removable plate is provided at the bottom which, when removed, gives access to the pot head, cable terminals, and potential transformer fuses. If the housing is mounted against the wall, access to these devices can be obtained by removing the truck.

advisable that the spare truck be of the same capacity as that of the largest feeder. If two types of breakers are used in the same switchboard, a spare truck for each type should be at hand.

When an oil circuit breaker with a greater interrupting capacity than those of the standard line of truck type panels is necessary, it is advisable to mount the breaker on a truck so that it can be moved in or out of the cell. It is much simpler and cheaper to make periodic examinations of the breaker mounted in this manner than with the stationary method of mounting, and, with spare breakers at hand, a substitution of the reserve breaker permits close, careful examination without the slightest risk of danger.

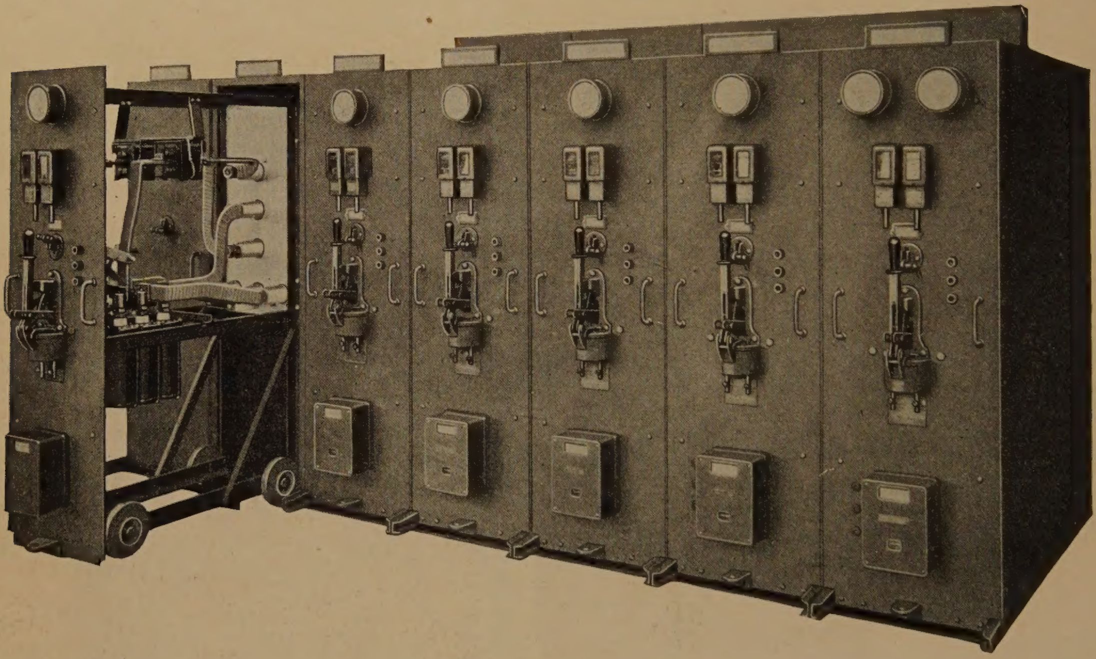

Fig. 2. Removable Truck in Disconnected Position

The housings, when assembled, make a continuous, rigid, structure. The trucks are interchangeable in housings designed for similar trucks, the interchangeability depending on the number of contacts between the elements, their arrangement, the capacity, and the width.

The truck and housing are interlocked, and the truck can be pushed into, or withdrawn, from the housing only when the oil circuit breaker is open.

If the oil circuit breakers are of the same type, trucks from 400 to 1200-ampere capacity are interchangeable, that is, the 1200-ampere truck can be pushed into a 400-ampere housing. Likewise, a 1200-ampere housing will take a 400-ampere truck. It is

Panels are available for the control of feeder circuits, generators and motors. For generators and motors of large capacity, the exciter and field controls are located on a stationary panel at the side of the generator or motor control truck. For moderate size machines, where the field current does not exceed 100 amperes, it is possible to mount the field ammeter and switch on the truck, thus doing away with the extra stationary panel. In this case extra secondary disconnecting devices are required for the field circuit.

Incoming line panels are equipped with an oil circuit breaker of suitable capacity, instruments, instrument transformers, etc., and are connected in circuit between the incoming conductors and the busbars.

Generator panels are similar, but have necessary synchronizing equipment, and may be supplemented by a stationary or non-removable panel adjacent, on and back of which is mounted the field switching and control equipment and such instruments as are required for field or exciter circuits.

Feeder panels are similar to incoming line panels except in relative capacity of breakers, or instruments and metering equipment.

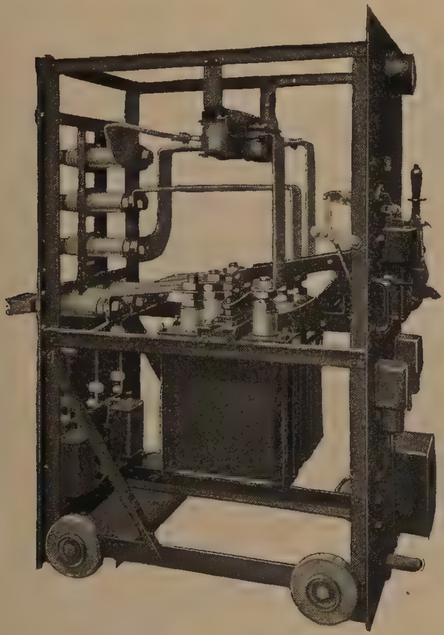

Fig. 3. Removable Truck with Electrical Equipment

Bus sectionalizing panels have disconnecting devices arranged in two sets, one set for connecting the oil circuit breaker to the ends of buses, and the other set connecting to the ends of other buses, or a continuation of the same bus, so that the two buses are connected through the oil circuit breaker, which therefore may be used to break the connection, or sectionalize the bus, when required. Due to the arrangement of disconnecting devices, such a truck panel is not interchangeable with the preceding types, or types similar to them.

Metering panels are similar to bus sectionalizing panels, except that no oil circuit breaker is used, the equipment consisting of instruments, meters, and instrument transformers. As there is no oil circuit breaker, the interlock must be utilized as a means of padlocking the panel in position, so that only an authorized person can remove it. This kind of panel is also non-interchangeable with other types.

Induction motor panels suitable for circuits up to 515 amperes, 7500 volts, are similar to feeder panels, having an oil circuit breaker, necessary instruments, etc., and with a starting compensator mounted in the truck, also necessary disconnecting devices. The circuit breaker is of double-throw construction and has an interrupting and a current carrying

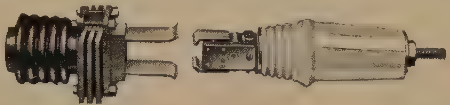

Fig. 4. Primary Disconnecting Device in Open Position

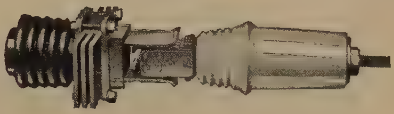

Fig. 5. Primary Disconnecting Device in Closed Position

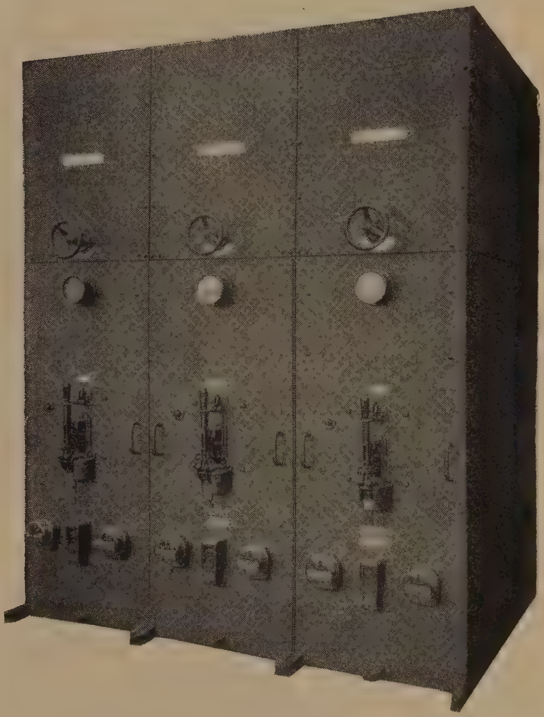

Fig. 6. Removable Truck Type Panel Switchboard, 3-phase, 3-wire, with Disconnecting Switches Operated by Hand Wheel Mounted in Superstructure

capacity equal to those of the oil circuit breaker used. One throw of the breaker places the compensator in circuit with the motor for starting, the other throw de-energizes the compensator and connects the motor directly to the buses.

Synchronous motor panels are similar to those for induction motors, the necessary field switching and control apparatus being added. Where the interrupting capacity of the double-throw motor-starting and running oil circuit breaker is sufficient for the requirements of the circuit it controls, no other oil circuit breaker is required for automatic protection, but in cases where greater interrupting capacity is necessary, another truck panel is installed adjacent, with a circuit breaker capable of rupturing the severest short-circuit or overload current possible on the circuit. This truck panel is a plain feeder type panel, and the motor-starting and running breaker is connected in series with it. The automatic overload devices are attached to the main breaker only. The two breakers in the truck panels being connected in series, no current can be interrupted at the disconnecting devices when either truck is withdrawn while the breaker in the other truck is closed, as it is necessary to trip the breaker before a truck can be withdrawn.

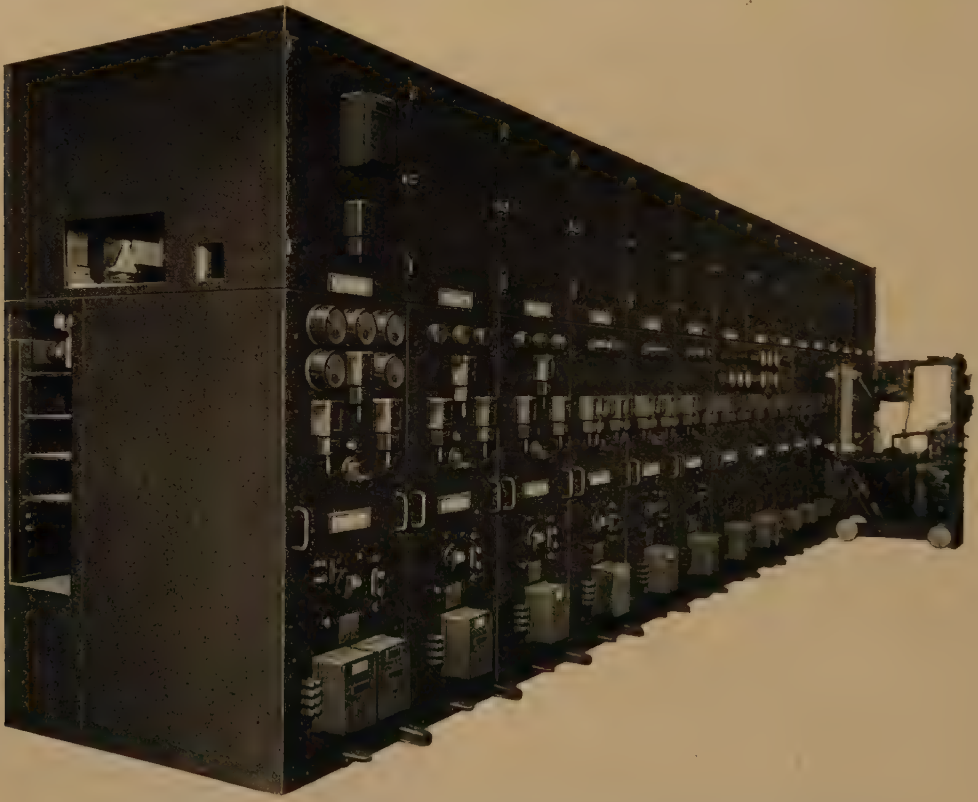
Fig. 7. Safety Enclosed Removable Truck Type Switchboard with Automatic Reclosing Feeder, Incoming Line, and Transformer Panels

The motor field rheostat, being a bulky device, is mounted on top of the stationary housing, with the operating handwheel on the truck panel; a simple arrangement is used for transmitting the motion from the removable truck panel portion of this mechanism to the stationary housing portion which is geared to the rheostat switch.

The compensator, which varies in size, according to the requirements of the motor circuit, may be mounted on the starting truck, if not too large, or it may be installed upon the stationary housing or elsewhere. The necessary connections from the compensator to the truck panel are made through disconnecting devices suitably arranged.

The increasing use of automatic reclosing equipment for alternating-current feeders has led to its inclusion in the list of equipments available in truck type panel mounting. In the case of this equipment the truck and housing are similar in construction and arrangement to the regular feeder type panels of the same capacities, and the dimensions are the same. The oil circuit breaker, instrument transformers, etc., are mounted inside the truck, the motor-operated breaker closing mechanism, control relays, and the control power switch being mounted on the front. In order to make the panel completely "dead front," the control power switch is of the two-button, pull-button type.

The function of the automatic reclosing equipment is to protect apparatus that is supplying current to feeders from damage due to short circuits or heavy sustained overloads, and at the same time insure continuity of power supply on the feeder under normal conditions.

A saving is at once apparent when comparing the cost of installing a truck type board with that of the open type board. All of the assembly work is done at the factory before shipment. The compartments are assembled and adjusted. The trucks and housings are shipped complete.

Installation comprises only the task of laying out the floor drilling plan, and drilling and bolting the housings to the floor and to adjacent housings, installing busbars and connecting cables. When the oil circuit breakers have been filled with oil, the board is ready.

A Vibration Recorder and Some of Its Applications

By Charles G. Beall, M.D.
Duemling Clinic, Fort Wayne, Ind.
and
Chester I. Hall
Fort Wayne Works, General Electric Co.

The authors describe a device for detecting and recording the characteristics of vibrations and tremors. One of the principal uses for this apparatus is found in the study of muscle tremors, a knowledge of which is becoming of increasing interest to the medical profession.—Editor.

The necessity of recording certain non-uniform vibrations has resulted in the development of a recording device of unusual construction which on test appears to fulfill the requirements for several different lines of investigation.

The particular problem which prompted the development was that of recording hand tremors, which have always attracted considerable attention among the members of the medical profession, especially in a clinical way.

These hand tremors consist of vibrations having amplitudes of $\frac{1}{16}$ to $\frac{3}{8}$ inches, and frequencies varying between 5 and 15 cycles per second. In general the means used to record these vibrations consists in attaching a point light source, very light in weight, to the patient's finger and then focusing the image of the source on a moving film so that the motions are somewhat magnified. The details of this construction and optical system are shown in Fig. 1 where A is the point light source and L_1 and L_2 the lenses for focusing the source on the movable drum D which carries the film. It is seen that the image focused by the lower lens follows the vertical component of the motion of the source, while the upper lens projects the horizontal component of the motion reflected from the 90-deg. mirror M.

The hemisphere A, called the light source, should more properly be called a secondary source since it is a highly polished hemispherical mirror formed on the end of a small rod of alloy steel. The primary light source is a standard 6-volt 32-candle-power Mazda C lamp, the rays passing through a condensing lens L_3 which projects a beam of parallel rays about three-fourths of an inch in diameter in which the patient is directed to hold the reflector. This parallel beam is of uniform intensity so that the image of the source reflected from the ball in any part of the field is of the same size and intensity, giving a very uniform line on the film.

Removal of all restraint to free motion of the ball assists in recording the true motion of the finger and makes possible the application of the device to other fields such as the study of the motion of the front sight of a rifle or revolver while being aimed (which would be valuable information for training marksmen), the investigation of vibrations of rotating machinery under starting and running conditions, and examination of similar motions which cannot be studied without first being recorded.

Application to the Study of Muscular Tremors

One of these devices has been installed at the Duemling Clinic,[*] Fort Wayne, and records have been taken of enough patients to substantiate former investigations[†] showing that it is possible to use the records in the diagnosis of certain diseases.

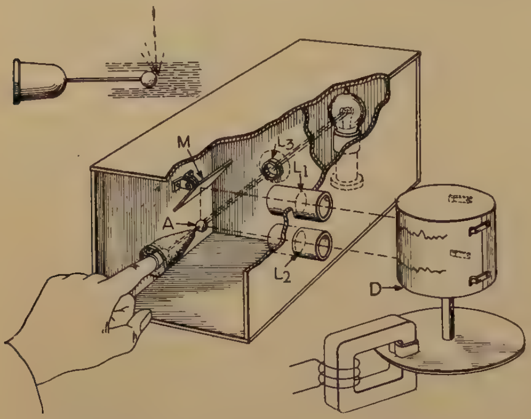

Fig. 1. Sketch of the vibration recorder with part cut away to show the paths of light beams from the source to the photographic film. The smaller upper sketch shows how the effect of a point source is obtained

Tremors of diagnostic importance occur not only in organic diseases of the nervous system, but also in certain other conditions. Physiology teaches that muscles in health are held in tone by mild impulses delivered into them along the motor nerves at the rate of about twelve a second. No tremor is then perceptible but if the impulses are of diminished frequency, are exaggerated or are irregular in force or rhythm, they become perceptible to the unaided eye or touch.

According to the immediate cause, tremors may be divided into three groups as follows:

I. Toxic tremors—including those due to tobacco, alcohol, alkaloids, metals, hyperthyroidism, and probably those due to exhaustion.

II. Organic tremors—embracing tremors due to brain lesions, general paresis, multiple sclerosis, posthemiplegic conditions, paralysis agitans and senility.

III. Functional tremors—including tremors due to fear, hysteria, neurasthenia and various other psychoneuroses (Crenshaw).

The records included in this article show very distinct differences between the organic tremor due to paralysis agitans and the functional tremor due to psychoneurosis. Other interesting points are indicated in the explanation accompanying the records.

Other Applications

A few films are also included which were taken by fastening the reflecting ball to the end of both rifle and revolver barrels held by expert marksmen and by poor marksmen. The differences there are very noticeable, the experts showing much greater control in being able to "hold" on a given point.

The application of the optical system of this recorder to physical laboratory experiments and physical apparatus in general will satisfy the demand for a practical point source of light of high efficiency.

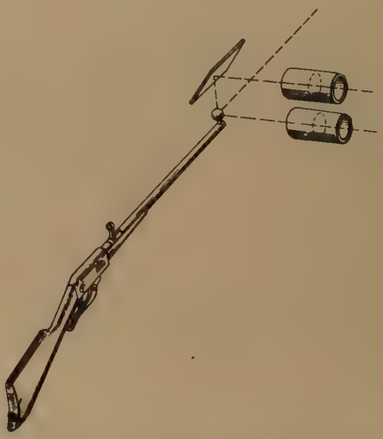

Fig. 2. Application of the principles of the vibration recorder to determine the ability of a marksman to "hold" a firearm on a target

VIBRATION RECORDER CHARTS

In each of the following charts the upper line records horizontal vibrations and the lower line shows vertical vibrations. Ordinates give the magnitude of vibrations, multiplied by two. Chart movement is from left to right at the rate of one inch per second.

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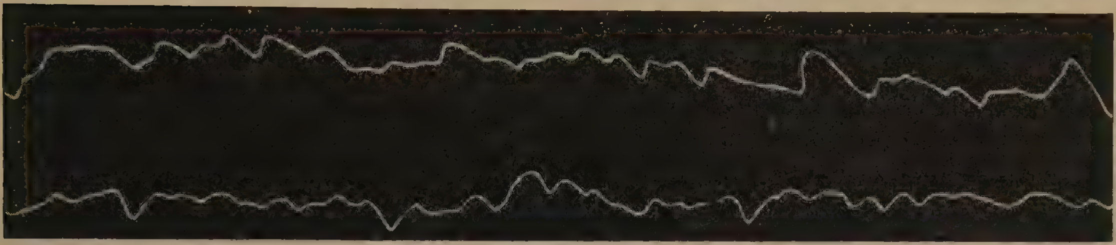
[*] The authors desire to express their thanks to Dr. C. C. Grandy, Roentgenologist, who assisted in making the records and allowed the unlimited use of his photographic equipment.

[†] Eshner (*Journal, Exp. Med.* 2:301, 1897); Bornstein & Saenger (*Deut. Ztsch. f. Nervenhlk.* 52, No. 1 and 2; 1–27, 1914).

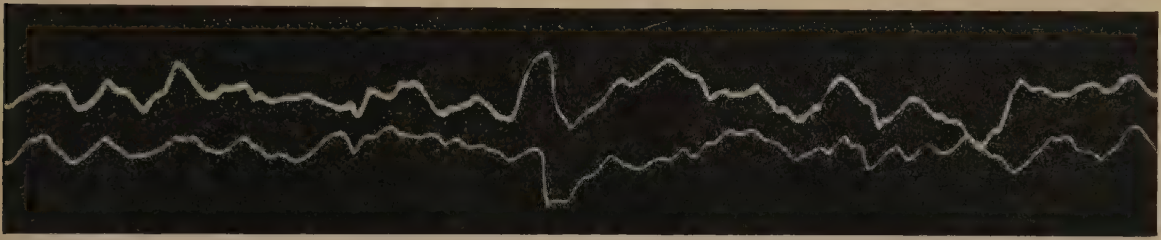
Former methods of making graphic records included some sort of mechanical connection between finger and stylus and therefore interfered with the free motion to some extent.

CLASS I—TOXIC TREMORS

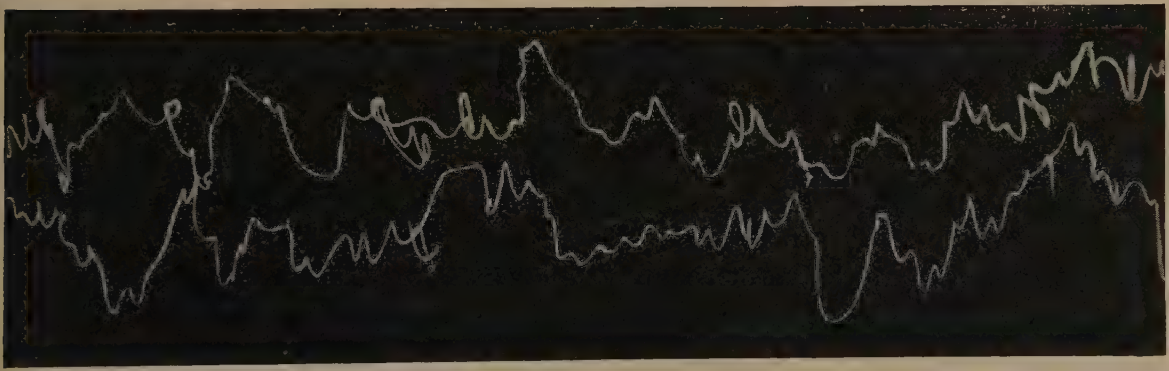
(Free Hand Vibrations)



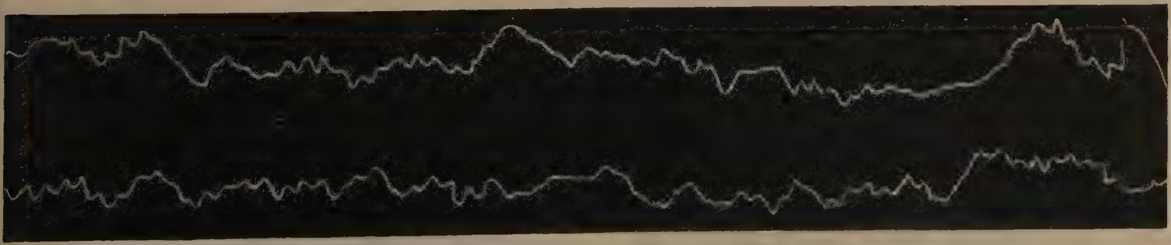
I (a) *Myxedema.* Basal metabolism, minus 34 per cent. The secretion of the thyroid gland is diminished and many body functions are slowed. Note the low rate 6 per second (normal rate 12 per second). Compare this with I (c), the opposite disease, in which there is an increase of the thyroid secretion and in which many body functions are speeded up.



I (b) Tremor of inveterate tobacco smoker.



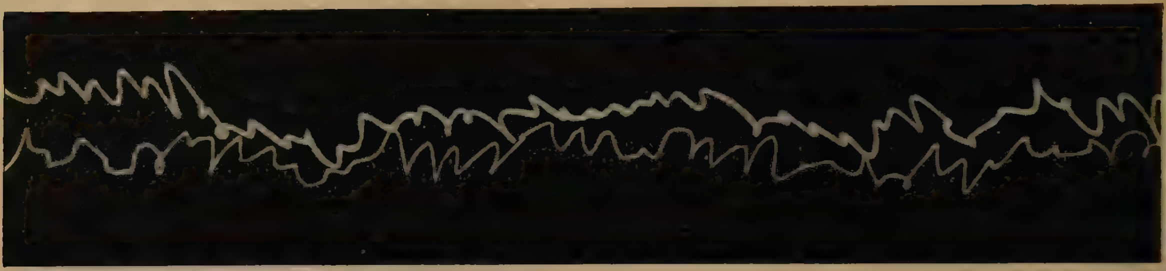
I (c) *Exophthalmic goiter*, severe. Note the great amplitude of the vibrations and the loops caused by rapid movements in the direction parallel to the motion of the film. Compare with I (a), the opposite disease.



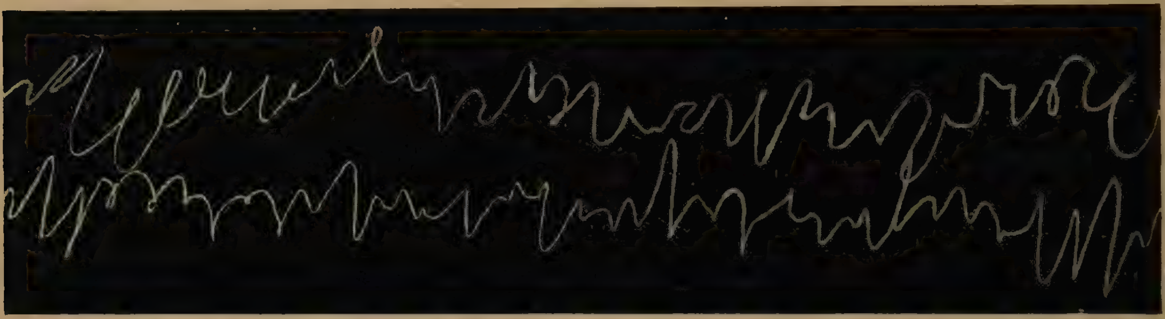
I (d) *Exophthalmic goiter*, mild. Note the same high frequency of vibrations but less amplitude, as compared to I (c).

CLASS II—ORGANIC TREMORS

(Free Hand Vibrations)



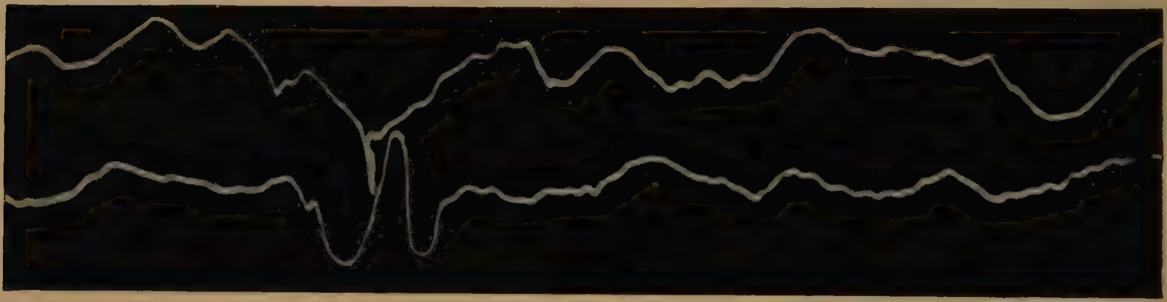
II (a) *Paralysis agitans.* Man of 45. Note that the rate is low, 6 per second, amplitude considerable, and movement irregular.



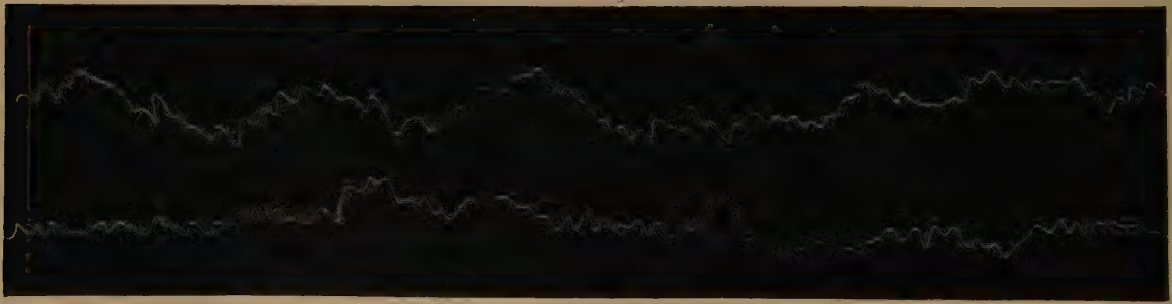
II (b) *Paralysis agitans.* Man of 52. The vibrations are of great amplitude but the rate is low.

CLASS III—FUNCTIONAL TREMORS

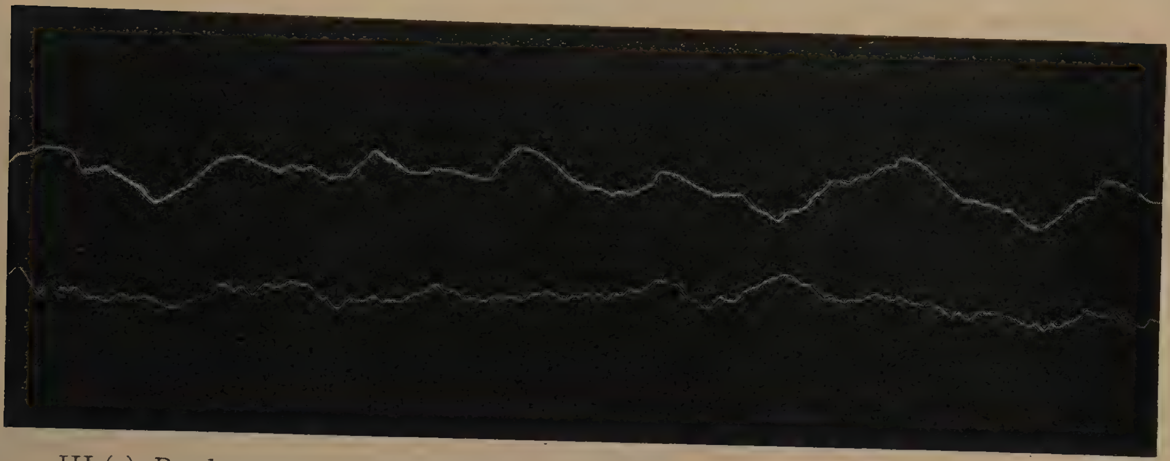
(Free Hand Vibrations)



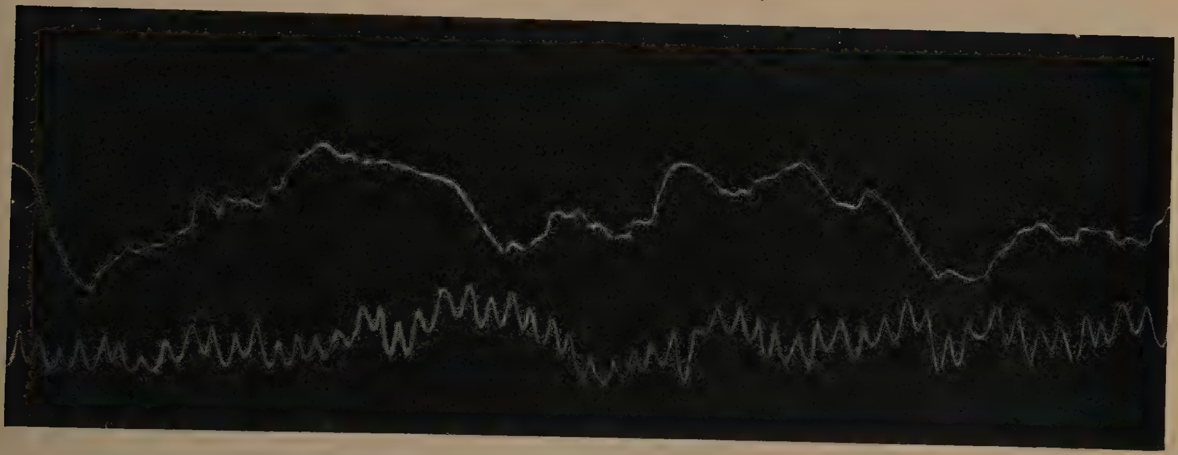
III (a) Sudden shock, caused by dropping glass plate behind patient. This record gives an indication of the time required for recovery from shock.



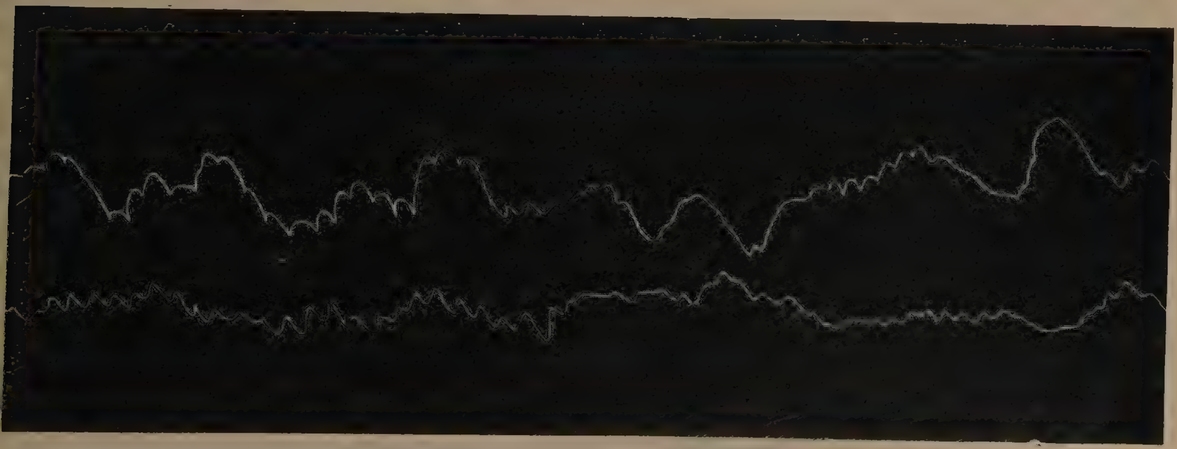
III (b) *Psychoneurosis.* Woman of 32.



III (c) *Psychoneurosis*. Man of 22.

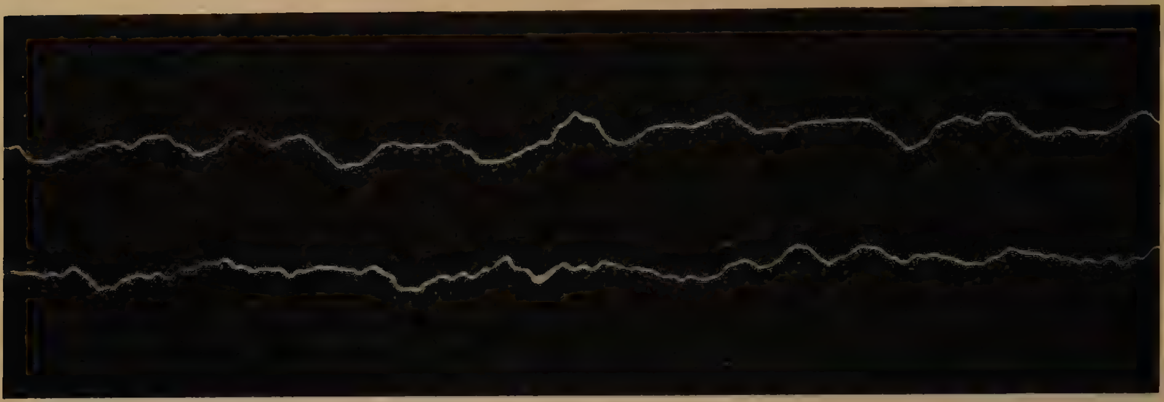


III (d) *Psychoneurosis*: Woman of 44. The vertical vibrations are of unusually constant amplitude.

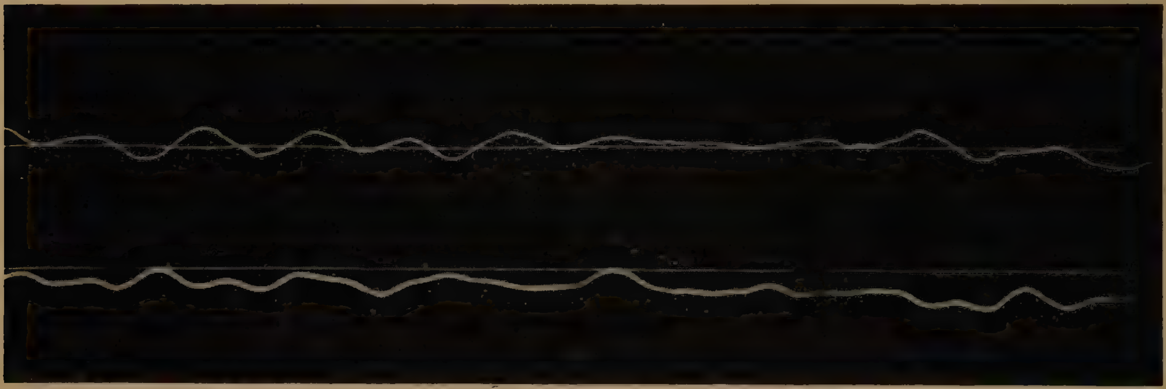


III (e) *Psychoneurosis*. Man of 29.

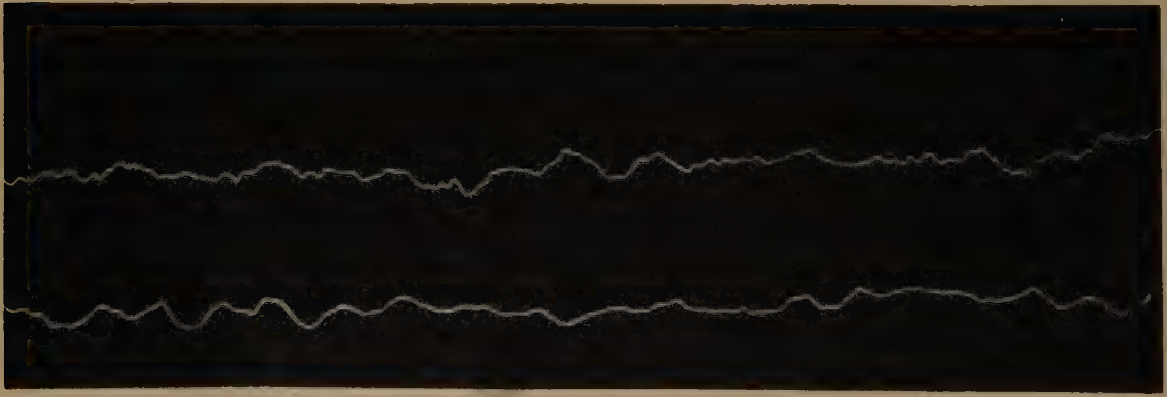
CLASS IV—MISCELLANEOUS



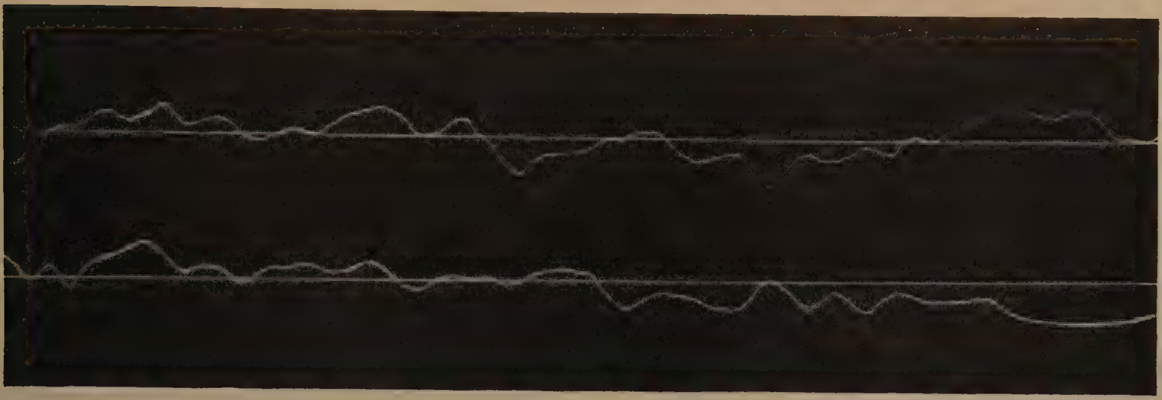
IV (a) Unsupported arm vibration of expert marksman No. 1. This chart indicates normal pathological vibration and should be compared with the preceding charts which show abnormal vibration.



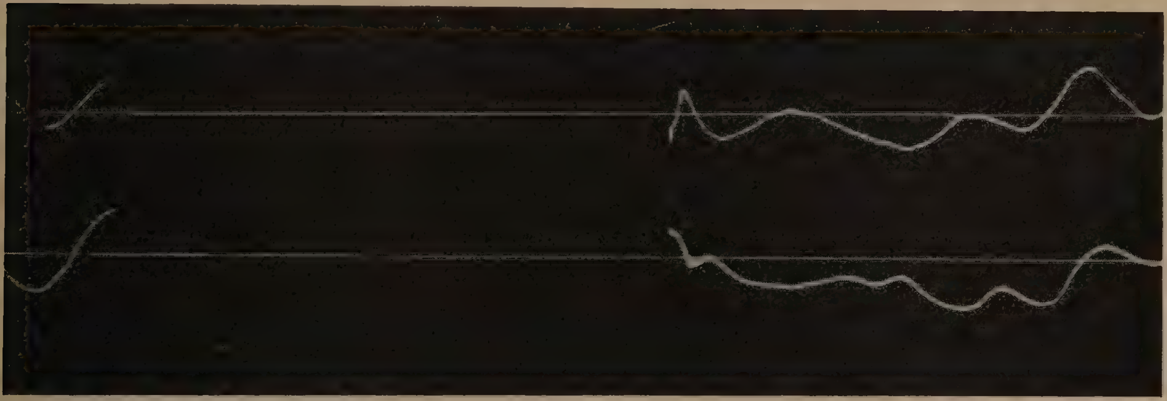
IV (b) Vibration of muzzle of rifle held by marksman No. 1. Note that the frequency is much lower than in IV (a) on account of the damping effect of the rifle's inertia. The straight lines indicate the center of the target.



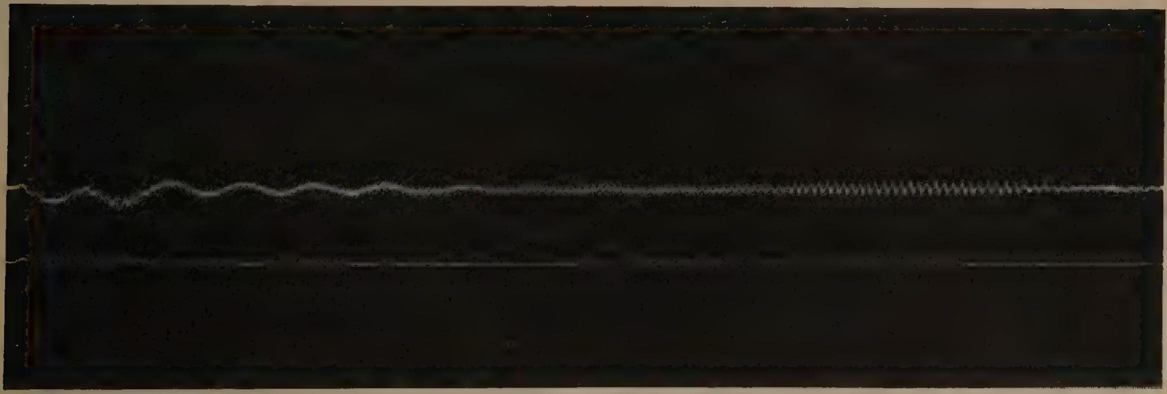
IV (c) Unsupported arm vibration of expert marksman No. 2.



IV (d) Muzzle of rifle held by marksman No. 2.



IV (e) Muzzle of rifle held by poor marksman. Note that record is incomplete, showing that marksman was unable to hold the muzzle within the field of the recorder.



IV (f) Vibration of an alternating current washing machine motor mounted on sponge rubber supports. The left side of chart shows the starting condition, the motor being shut off at a point somewhat to the left of center of chart, the remainder representing coasting. The vibration is caused by rotor unbalance, the waves at the beginning being due to the movement of the stator resulting from the reaction between rotor and stator. Notice that the amplitude of the horizontal vibration was greater after the motor speed had been reduced to a certain value, at which the frequency of the vibration due to unbalance was the same as the natural frequency of the system.

Street Lighting Glassware

By Frank Benford

Physicist, Illuminating Engineering Laboratory, General Electric Company

Not so many years ago street lighting glassware consisted of the panels in the four-sided gas lamp and the spherical enclosing globe of the open carbon lamp. In these the primary function was to protect the light source from the weather without shutting off the distribution of light. From them our modern street lighting glassware has been developed—a remarkable accomplishment of art and science combined. A more or less unsightly object has been made beautiful and a wasteful utilization has been properly controlled. Unaltered by retouching, the half-tone illustrations in this article present as accurately as is possible photographically the composite work of the artist, glassworker, engineer, physicist, and psychologist.—Editor.

Each art and profession has a stock of everyday words to which it has given a special meaning. Among artists, "interesting" is such a word. A simple curved line, if it is graceful, appropriate, and pleasing is interesting because it will attract a second glance. Even an arrangement of straight lines may be "interesting." The designer of so simple a thing as a globe for a street lamp thus has within his reach all the elements of a form that may be interesting because of its simplicity and beauty. And this result may be attained without any tendency toward the unique or startling, for quiet dignity is being insistently demanded and rapidly becoming a prime feature in the illuminating art. If there must be a battle-cry for the designer nothing could better serve than "Simplicity—Interest—Dignity," since these three words express the purely artistic goals of the designer, for artist he must indeed be.

The artist, however, has not free rein in his creation of a globe design, for the requirements of many other people must be considered. The ultimate purpose of a lamp and a globe is to produce certain conditions for the eye, and therefore we may expect a wide range of requirements that can be easily stated but not so easily explained. The eye is the most studied and almost the least understood of human organs. Thus we are all strongly attracted by anything that sparkles, or moves. The fascination of these two things, sparkle and motion, may be carried even to the extreme of producing hypnosis, but even the most hardened lighting enthusiast usually has sufficient self control to stop short of putting the customer into a trance while he sets his signature on the dotted line. To a certain extent, sparkle and motion are interchangeable and this fact has been applied with great profit to globe design.

The light of an arc lamp varies from that of an incandescent lamp in at least three respects. First, there is a great concentration of energy and a high brilliancy in the arc that is not closely approached by the incandescent filament. Second, there is a color difference; the arc in general being white or blue-white against the more mellow yellow-white of the incandescent. Third, there is the flicker and variation of the arc as compared with the perfect steadiness of the light from the incandescent lamp. All three of these features must be taken into account in globe design, but for the moment let us consider the question of steadiness and the influence it has had in glassware design.

In the early days of the carbon arc lamp its most objectionable feature, from the point of view of the consumer at least, was the flicker. The word flicker is too narrow to describe properly the actions of the original arc lamps, for in addition to an occasional quivering of the light in a given direction from the lamp, the light went through a regular lunar cycle of full light, half light, quarter light, and no light. The disadvantages of this cycle of change were quite obvious to even a public inclined to be lenient to an object of such good service as a street light. The arc was soon steadied by the development of the luminous lamp with new electrodes and improved lamp mechanisms, but the remaining flicker was held in disrepute largely on account of its former association with the larger cycles of change that had now been overcome. With the development of larger and better incandescent lamps the arc seemed doomed. Many people anticipated the day, or rather night, when the last flickering arc would be taken off its standard, stored away in a museum and replaced by a perfectly steady incandescent lamp. Just when this great change seemed most likely to come about a strange thing happened. It was discovered, and this by psychologists and other disinterested people, that within easily-kept limits the flicker of the arc is of pronounced benefit in street illumination. The quiver of the light was found to assist greatly in maintaining mental alertness, and it gave to the surrounding objects a certain appearance

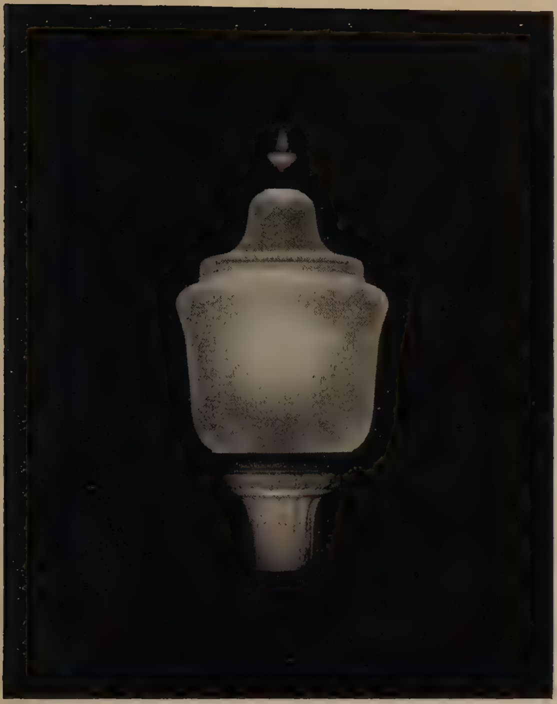


Fig. 1. A night view of a globe that substitutes glamour for glare and radiates beauty as well as light

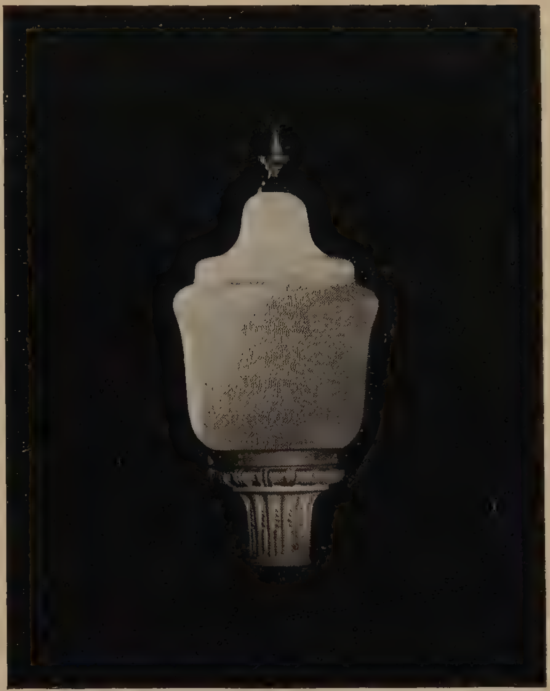


Fig. 2. A day view of a unit notable for grace of outline and a certain softness of surface texture

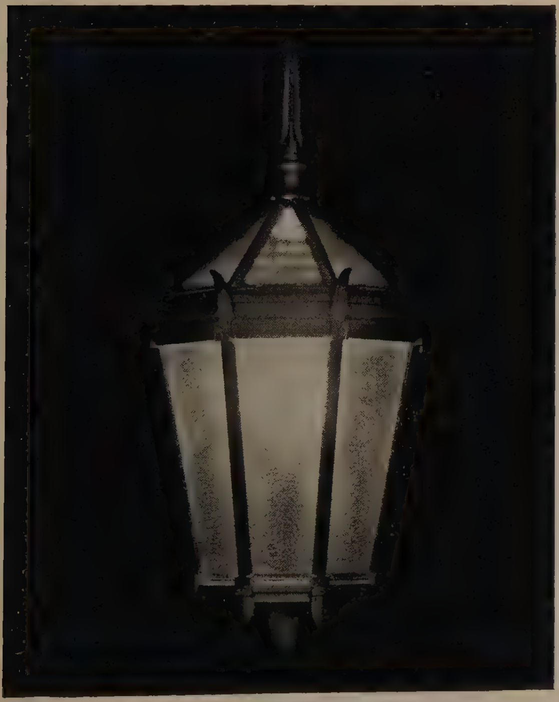


Fig. 3. There are two reasons for horns on a lantern; they look well and they have always been there

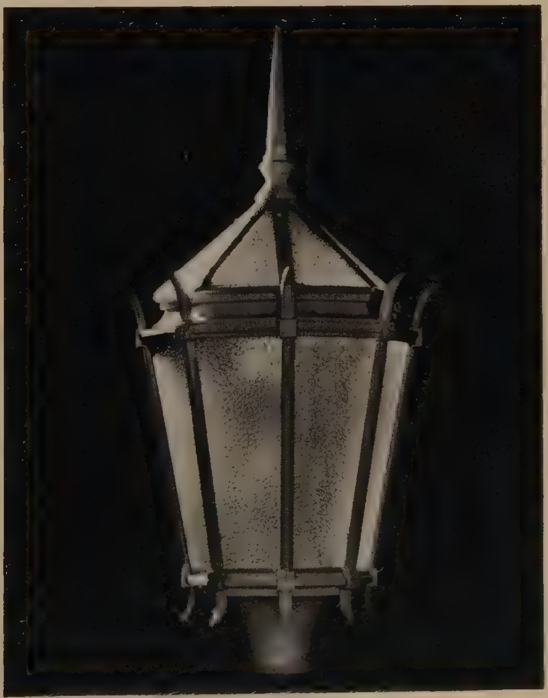


Fig. 4. The decided martial tone of this venerable design requires a substantial looking glass to keep it in balance

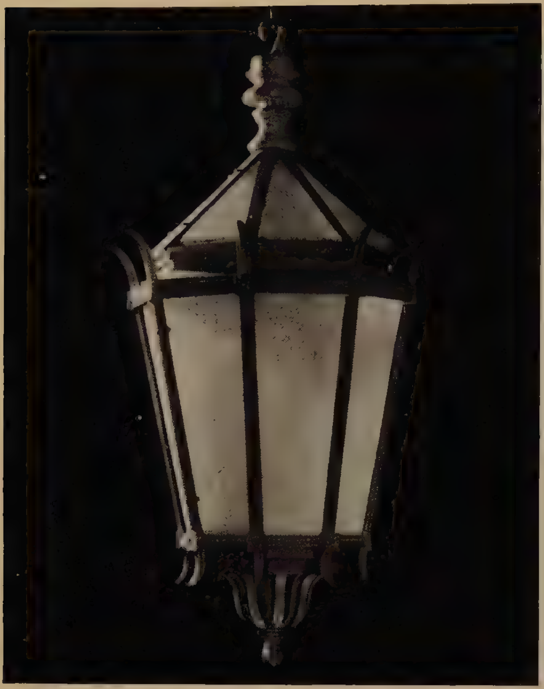


Fig. 5. A pendant lantern that might have hung at the gate of a medieval castle—the light within is another story

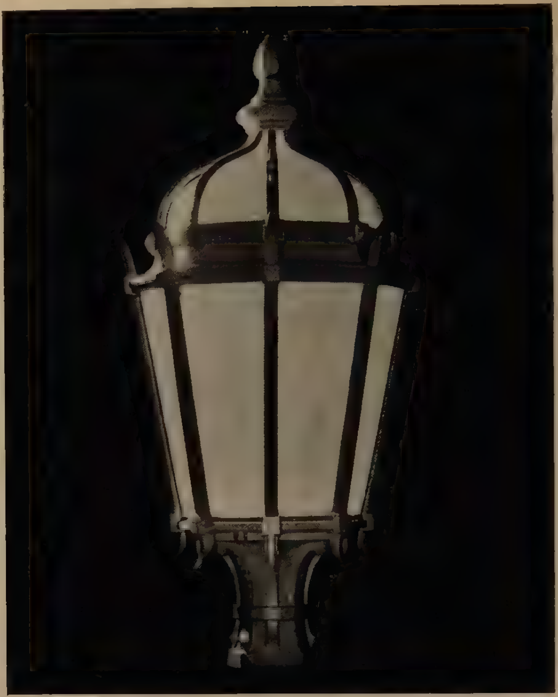


Fig. 6. The marble-like texture of the glass and the grace of the dome give this lantern a less military tone than usual

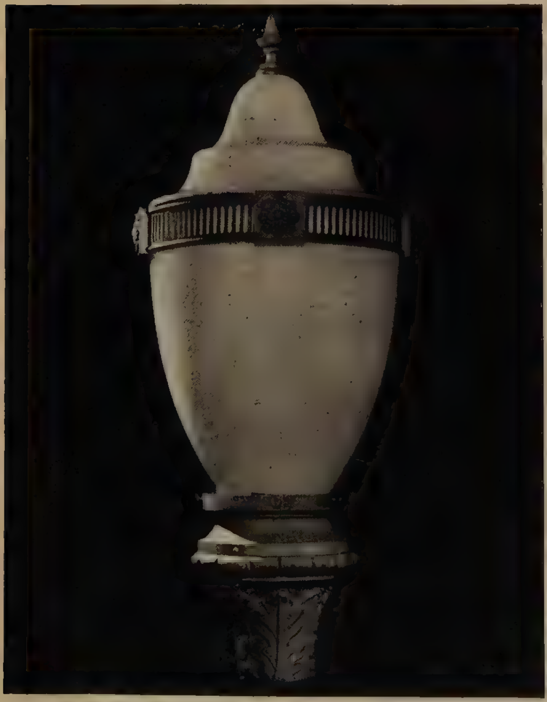


Fig. 7. To the graceful lines of this globe are added the ornamental tone of the band and finial

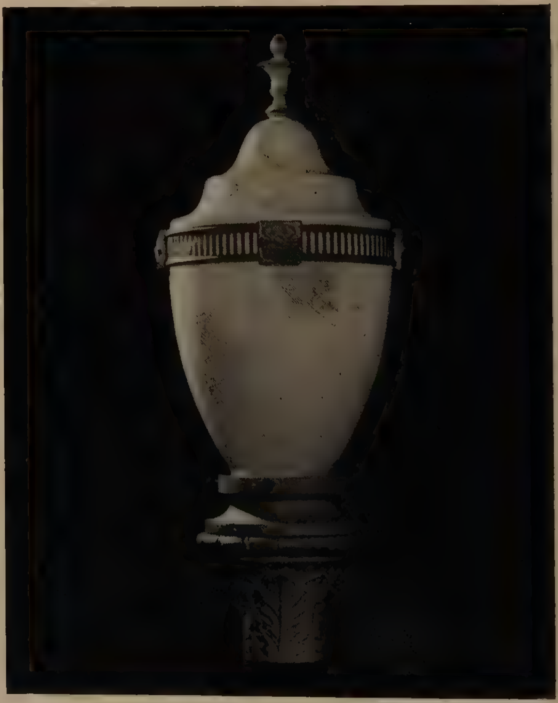


Fig. 8. This dignified unit is similar in design, but slightly smaller than the unit in Fig. 7

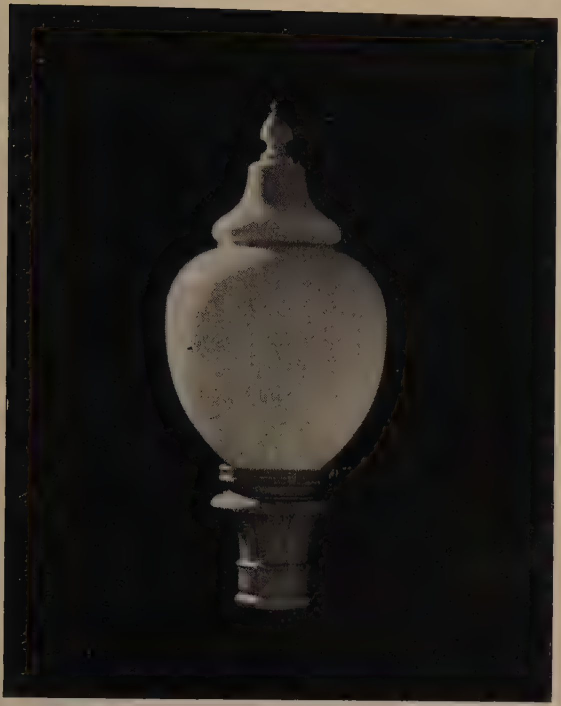


Fig. 9. This unit of simple and neat design is at home on a street of homes

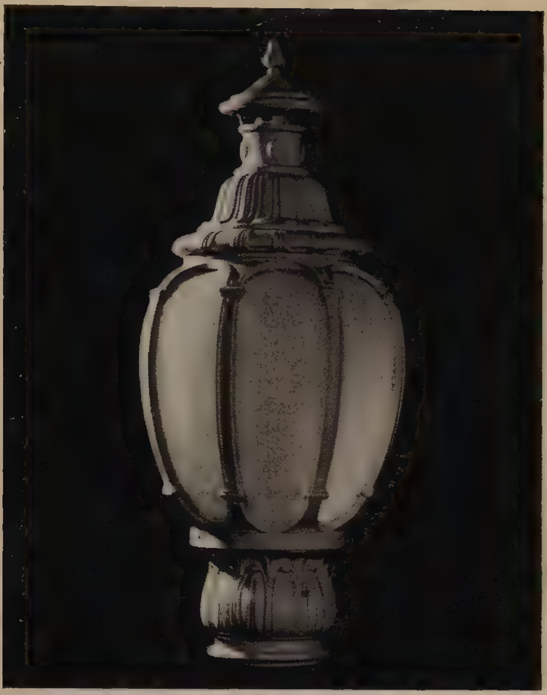


Fig. 10. The rugged appearance of this unit is in keeping with its power as an illuminant

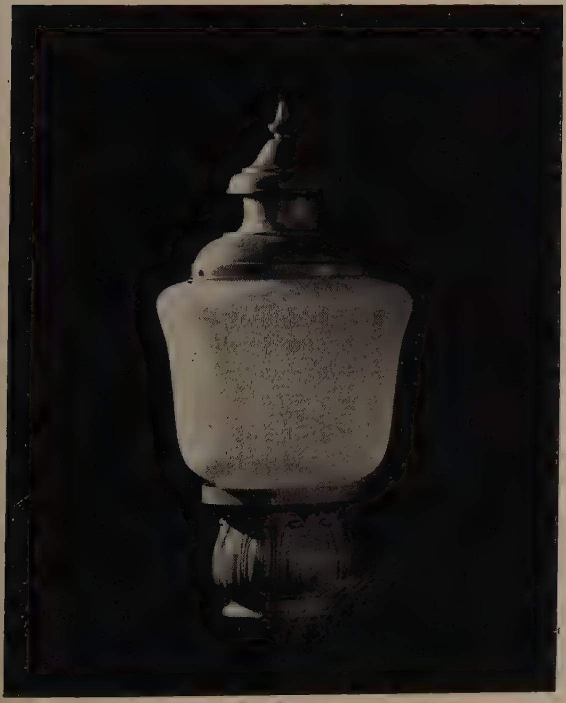


Fig. 11. A pleasing combination of metal and glass that shows unity of purpose and design

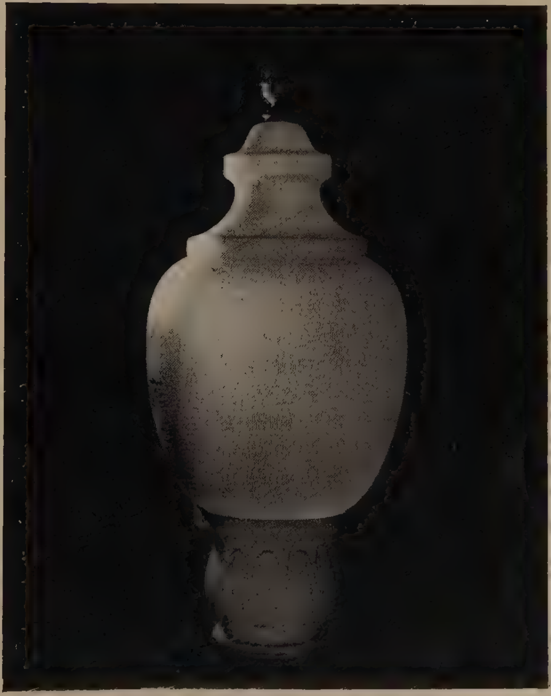


Fig. 12. The lineage of this globe can readily be traced from modern America to ancient Greece

of life that is often greatly desired. It is even asserted by certain veracious observers that at about this time the street arcs were observed to give several additional winks in the course of a night's burning. Considerable experimenting was carried out along this line, and in addition to the new found use for the natural flicker of the arc there was found to be some valid objections to a perfect uniformity of street illumination. These two features meant much in the street lighting art and they helped in discovering the natural boundaries of service for the arc and incandescent with the latter seemingly at a disadvantage at that time.

The sparkle of a diamond, or the sheen of silk, is closely related to the flicker of the arc, related at least in the effects they have on the observer. They all attract our attention and give us in some way a sense of well-being. To us a brilliant glass chandelier is twice as attractive when the glass prisms swing or when in walking near them the individual prisms light up and fade. Here we have a perfectly steady light giving a sparkle or flicker due to the change in relation between the observer and the glass. So far as effect is concerned the two flickers, the real and the induced one, differ only in degree. Both give a feeling of life and animation, and the observer in a wholly unconscious manner takes on some of the animation he perceives in the swinging glass. This principle of animation through the breaking up of the light into minute beams was eagerly seized upon by the street lighting enthusiast and the battle for supremacy was on once more; but there was this difference, the arc was to be merely subjugated, not annihilated and utterly cast out. The battle will end when each type of light proves its peculiar fitness for certain definite purposes and as time goes on the zones of superiority for each unit are becoming more and more clearly outlined, with always a contested region between.

In Figs. 1 and 3 are illustrated (as well as may be with photographs) the application of the sparkle principle to a globe and to a lantern. The globe has a rippled outer surface and these ripples act as miniature searchlights sending minute beams in all directions. The variation of illumination around the globe may be too small for measurement but the eye readily picks up these little beams and animation results. Looking directly at the globe the light source is concealed behind a sparkling crystal wall having a generally soft texture with central points of high brilliancy spread over a considerable area. The least movement of the head results in the disappearance of some of the sparkles and the appearance of others. The irregular form of the ripples prevents the appearance of any fixed geometric pattern and the whole effect may be described as having "Simplicity—Interest—Dignity."

The same two units in the daytime lose none of their individuality, for although there is some change in glass texture due to the light falling on the outside in place of originating within still the beauty of a simple curve remains in one and the dignity of the straight line is found in the other, and if the casual passer-by gives them a second interested glance of approval we may be content, for they are an artistic success.

Another type of surface texture is illustrated in Fig. 5 where the glass is diffusing and in addition has a broken surface that gives it a highly interesting texture. A denser diffusing glass with a rippled surface is shown in Fig. 6. Here the ripple is greatly subdued and shows just enough to relieve the surface from absolute flatness. The daytime appearance of this unit is particularly good for it brings out strongly the iron work of the lantern. This feature of appearance in the day is of as much importance as the night appearance, for it is by day that the whole standard and lighting unit come most readily to our attention.

The day has long departed when lighting units were designed wholly for photometric efficiency. From a six-hour unit we have come to a twenty-four-hour unit, and this has been brought about by the co-operation of engineer, artist, physicist, and psychologist. There has been plenty of good-natured disagreements for each party has a somewhat restricted field of vision, but out of the numerous discussions and exchanges of views there has come much good and today we have plenty of examples of both beauty and utility being served by the same piece of glassware.

An excellent example of the change that has come over our point of view is found in the recent great decrease in the number of street illumination tests. The photometric data are almost wholly determined in a laboratory, and the performance on the street is judged by observers actually riding and walking along the streets and sidewalks and noting how clear and comfortable their view of essential objects may be. Many units that give wonderful illumination values are rightfully rejected by this test, which is after all the real engineering criterion, for the object of street lighting is to produce comfortable and safe illumination, not some specified quantity of light on the street. A unit that is inclined to glare has a hard time getting by this trial, and its photometric efficiency is wisely taken as an item of secondary importance.

It would be perfectly possible to write a book on "Etiquette for Street Lighting Glassware" for the things that are good have been fairly well sifted from the things that are bad. A globe is in some respects like a small boy. They both have a natural tendency to get dirty, but in both we may implant a counter tendency to keep clean. In the rippled globes it will be noticed that the ripples are arranged in a generally vertical direction. There are no horizontal flat surfaces where dirt may collect, and an occasional rain will serve to keep the surface fairly clean. The cross ripples where two vertical ridges meet are always at the foot of a valley or natural water channel, and what dust may lodge there does not survive the first freshet. The globe thus obeys a very important rule of conduct—"Keep Clean."

A second rule for street glassware is—"Conceal the lamp." This is done either by using a diffusing glass, or a clear glass with a rippled or otherwise broken surface, or more often by a combination of the two. This concealment must be carried out by day as well as by night, for the lamp itself is seldom a thing of beauty and no good purpose is served by letting it be seen.

A third rule is—"Be efficient." If this were the only rule we would use clear glass, but concealment of the light source is of high importance; and, as in human conduct, the height of efficiency is not always compatible with some of the finer graces of society. The efficiency rule is therefore gradually slipping into the background, and it may well do this for the generation of "raw" light has reached the stage where light may profitably be traded off for other things.

Rule number four is—"Be brilliant, but be careful." No one objects to a globe being bright but it must not be so bright as to be a source of glare; for when glare occurs the illuminating value is cancelled and entirely aside from the obstructions to vision there is both danger and unsightliness where there should be safety and ornamentation.

The fifth rule is—"Be ornamental." At night the globe alone is visible, the other parts of the standard are seen almost entirely in silhouette. The diffusion and texture of the glass are here most strongly accentuated, but in the daytime the outline of the globe is seen along with the entire standard or other metal parts. The ornamental features of the standard can now be seen in comparison with the form and texture of the glass and there must be coherence and unity, that is, the glass and metal most show that they were designed to go together.

The sixth rule is—"Be strong." Globes may be broken by overheating, by sudden cooling, and in cleaning. A globe made extremely thin will withstand the heat of a thousand or fifteen hundred watt lamp but it is likely to be broken in shipment or in cleaning. A thick globe will stand handling but may break at the first shower. Between the two extremes is the economic mean, and the designer must find this economic thickness and then see that the density of the glass gives the proper diffusion.

It is evident from the foregoing list that the globe designer does not concentrate his entire attention on the light radiating properties of the globe. The ever-present tax payer observes by day as well as by night, and as he knows he must pay the bill he usually decides he wants something both useful to his vision and pleasing to his sight. Hence, regardless of what the prime purpose of the globe may be, it must be pleasing in the sunshine as well as effective in the moonlight. Thus the designer often works at cross purposes, for the things that add to the daylight attractiveness of a globe may seriously detract from its night effectiveness. Here is a task for the designer that calls for all his skill, and a twenty-four-hour unit is possible only to him who can call to his aid the best talent in artistic design, skill in glass working, and care in the design of auxiliary parts, and it is solely by the closest co-operation of these three elements that he can hope to succeed.

There is an important distinction to be drawn between the metal and glassware of a unit and the lamp that they enclose. The lamp has a number of things to do, but the first and most important thing is to generate light. Higher lamp efficiency is still demanded and perhaps will continue to be a profitable subject for research for many years to come. The gains in lamp efficiency will not always appear as an increase in unit photometric efficiency, but they will contribute to all the various things the complete unit must be and do. There is a general rule connecting the *total* light output of a unit with the other

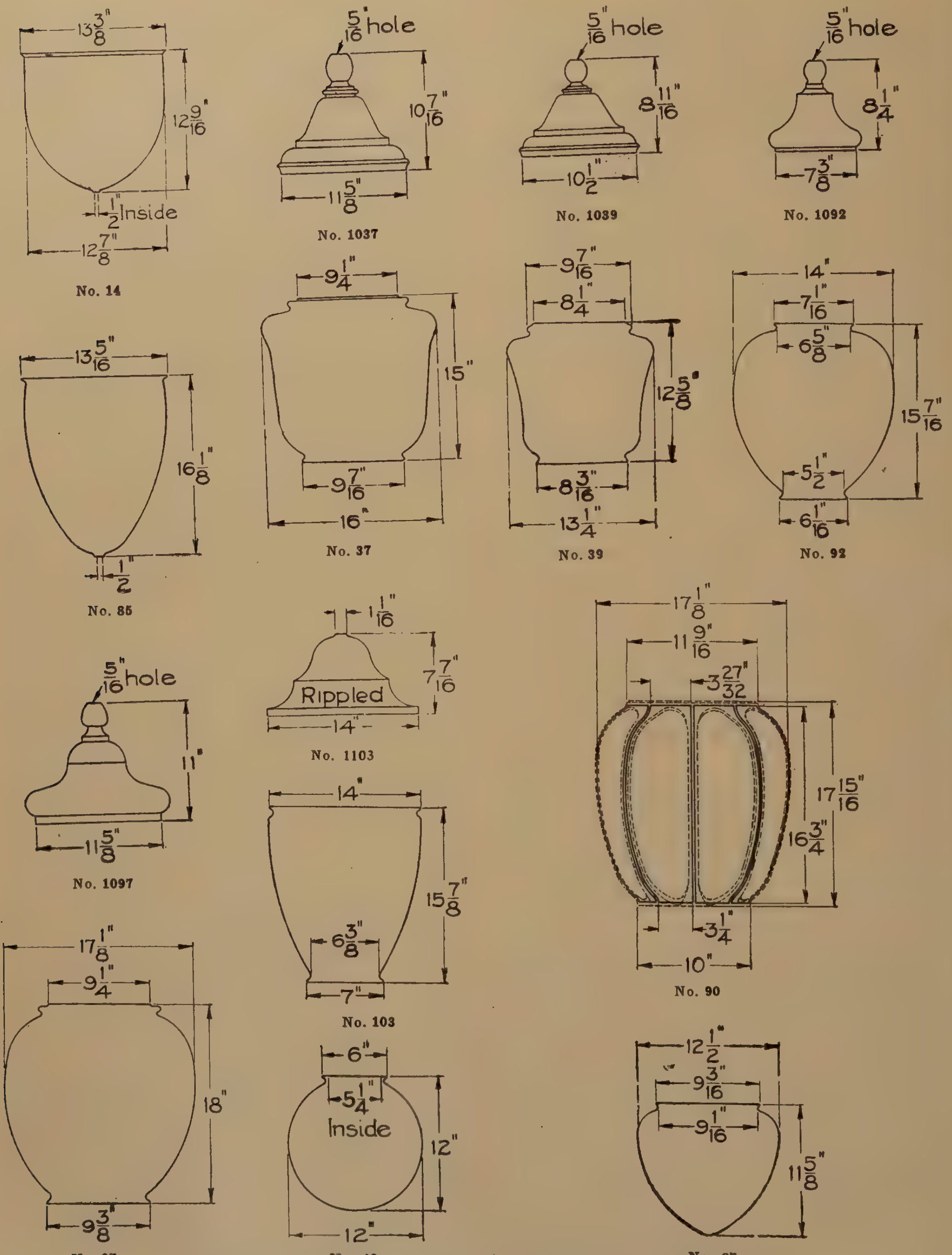
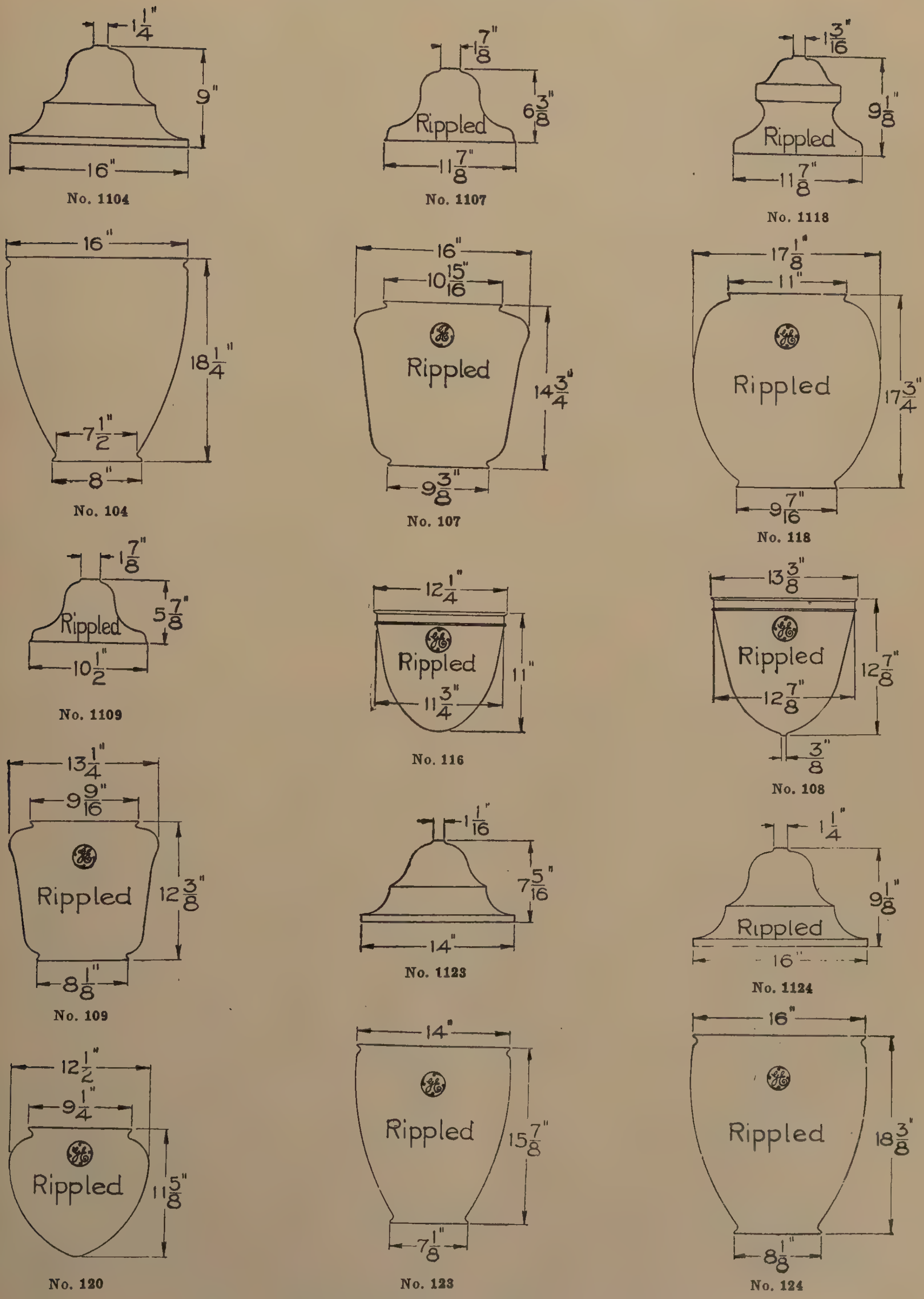

No. 14 No. 1037 No. 1039 No. 1092 No. 85 No. 37 No. 39 No. 92 No. 1103 No. 1097 No. 90 No. 103 No. 97 No. 43 No. 87

Fig. 13. Typical examples of modern street lighting globes and canopies



No. 1104 No. 1107 No. 1118

No. 104 No. 107 No. 118

No. 1109 No. 116 No. 108

No. 109 No. 1123 No. 1124

No. 120 No. 123 No. 124

Fig. 14. Typical examples of modern street lighting globes and canopies

desirable features, but this rule must not be rigidly applied to the *useful* output which is often a totally different quantity. This rule is: *Every advantage in appearance, distribution of light, or adaptation to some particular purpose is paid for ultimately in light.* The reason for this is fairly obvious, for every reflecting or transmitting surface is an absorber of light, and if we reflect, diffuse, or refract the light we must pay, for this is a tax that cannot be avoided. The rule holds true even as to the degree of loss. As an example, light can be more economically projected into a twenty-degree searchlight beam than into a ten-degree beam, and while the useful light may increase the total light decreases. If we aim at softness of diffusion the best diffuser is the most wasteful. The successful globe designer is the one who does not pay too much for his effects.

Cia Paulista de Estradas de Ferro

ELECTRIC OPERATION ON THE FIRST STEAM RAILWAY IN BRAZIL TO ADOPT ELECTRIC TRACTION

By Guy Bellows

Railway Engineering Department, General Electric Company

In November, 1914, the Review published an article by J. B. Cox giving most convincing statistics as to the superiority of electric over steam operation on the Butte, Anaconda & Pacific Railway. In the following article, the author gives a similar comparison of operating costs on the Paulista Railway of Brazil. The figures were compiled under the direction of Dr. F. de Monlevade whose position corresponds to that of General Manager, or Vice President in charge of operation on railroads in the United States.—Editor.

In the early part of 1920 the Paulista Railway, after studying all the then existing steam railway electrifications in Europe and the United States, decided to electrify its lines between Jundiahy and Campinas. Three thousand volts direct current was decided upon as being the best suited to their requirements from the experience of existing installations. Much credit should be given to Dr. F. de Monlevade, Inspector Geral da Cia Paulista, for his study and report on the electrification; and credit is also due the Officers and Directors of the Company who decided to carry out the first electrification of steam railways in Brazil.

Dr. F. de Monlevade, Inspector Geral, of the Paulista Railway

The section of the line selected is double track and to a certain measure is the throat of the traffic from the interior of Brazil. While the Paulista Railway does not actually run into the city of Sao Paulo, the connecting link being the Sao Paulo Railway (double track), this section of the Paulista Railway handles all the traffic from its feeders and the Mogyana Railway from Campinas. The chief point in favor of adopting electric traction was the high cost of fuel.

Both coal and wood are used. Coal is imported and wood is gradually growing more difficult to obtain with prices increasing in proportion. Therefore the economy to be obtained by electrification was well established.

Power for the electrification was contracted for with the Sao Paulo Light and Power Company. The material for the electrification was imported from the United States* and consisted of 10 miles of 88,000-volt double transmission line, 4500 kw. substation equipment, 27.3 route miles of double track, 3000-volt direct current trolley, the distribution system and 16 locomotives. The total cost of the electrification, including all material, erection, construction, etc., was approximately $3,000,000.

The substation is equipped with three motor-generator sets, each of 1500 kw., making a

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*See General Electric Review, July, 1921.
See *Electric Railway Journal*, June 11, 1921.

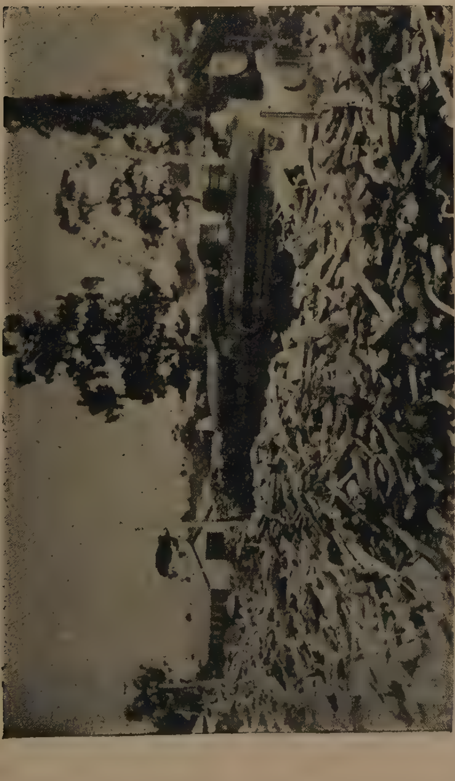

Fig. 1. A large part of the fuel used by steam locomotives on the Paulista Railway is native wood because of the high cost of imported coal. Illustration shows one of the wood piles with a wood-burning locomotive being refueled

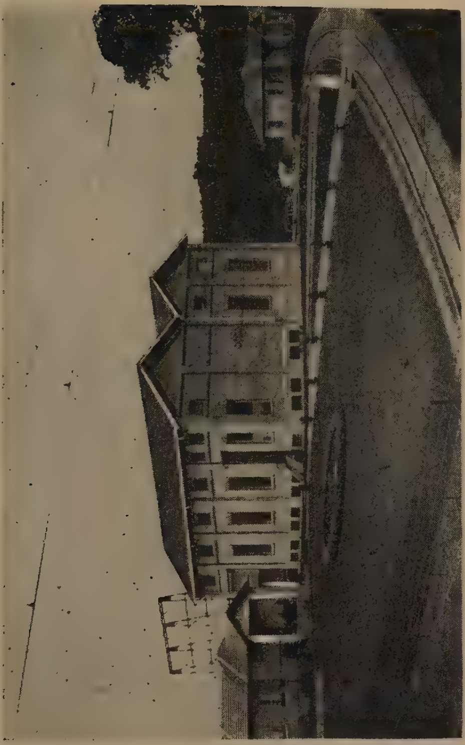

Fig. 2. The entire electric zone as initially operated on the Paulista Railway, consisting of about 28 miles of double track, is furnished from a single substation located at Louveira. The equipment consists of three 1500-kw., 3000-volt synchronous motor-generator sets taking power from an 88,000-volt high tension line

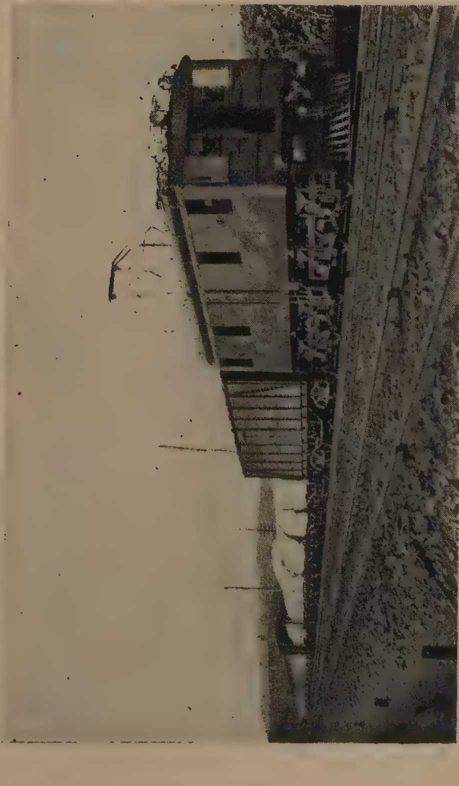

Fig. 3. A large part of the freight traffic handled by the Paulista Railway consists of live stock from the interior and coffee from the various plantations on this road and connecting lines. The coffee is carried on flat cars covered by tarpaulins

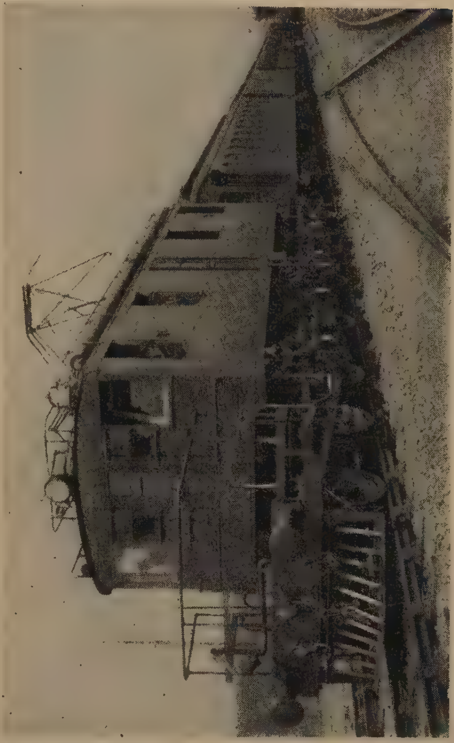

Fig. 4. Passenger service on the Paulista is equal in every way to that furnished by main lines in the United States, including sleeping and dining car service

total continuous capacity of 4500 kw., or 6750 kw. for two hours. The locomotives consisted of ten freight locomotives and six passenger locomotives. The freight equipment was built for handling 700-ton (metric) trains and the passenger locomotives for 400-ton trains.

Electric service was started in November, 1921, on the part of the line then completed and continued in steps until the completed zone was inaugurated in June, 1922.

A comparison of the traffic at the beginning of the electric service with the final service after electric traction had been finally put in full operation is interesting. All freight trains are scheduled and run regularly and the schedule is maintained to a surprising degree of accuracy. When the electric service was started the schedule provided for 16 passenger trains and 50 freight, the latter including two of mixed service. After the electrification had been completed, the schedule was maintained for 20 passenger trains and 28 freight trains.

TABLE I

Class of Service	Kw-hr. Motoring	Kw-hr. Regenerating	Per Cent Regenerating
Passenger ...	303,510	30,505	10.05
Freight	363,595	57,530	15.82
Total ...	667,105	88,035	......
Average per cent regeneration....			13.20

TABLE II

AVERAGES OF SPECIAL TESTS—FREIGHT AND PASSENGER SERVICE
CIA PAULISTA DE ESTRADAS DE FERRO

	Freight Service	Passenger Service
Distance of run, kilometers	44	44
Weight of locomotive, tons metric	90	109
Tonnage of trailing train	646	413
Tonnage of total train	736	522
Ton-kilometers trailing	28,438	18,172
Ton-kilometers total	32,398	22,968
Kw-hr. input at locomotives	571.8	509.0
Kw-hr. regenerated at locomotive	156.8	73.0
Kw-hr. net at locomotive	415.0	436.0
Per cent regeneration	27.38	14.3
Net watthours per trailing ton-km	14.59	23.95
Net watthours per total ton-km	12.81	18.95
Number of runs	5	12
Number of cars in train	22	12
Number of delays or stops per run	0.6	1.0
Total time of run in minutes	73.4	44.75
Time delay on stops, minutes	4.2	2.0
Running time, minutes	69.2	42.8
Maximum speed, k.p.h	50.0	80.0
Average speed, k.p.h	38.2	61.7

The railway company made a careful study of the service on the electrified zone as compared with steam operation, on the basis of one year's operation, equivalent to 465,750 miles. Table III shows the cost of operation for steam operation and Table IV shows cost of electric per train mile.

TABLE III

COST OF STEAM OPERATION

	Total Cost 465,750 Train Miles	Per Train Mile
Coal—20,000 tons (metric)	$238,095	51.14c.
Engine drivers and firemen	29,762	6.38
Mechanics and helpers (running maintenance)	13,227	2.84
Locomotive wipers	2,679	0.57
Lubricants and miscellaneous material	10,089	2.16
Total	$293,852	63.09c.

TABLE IV

COST OF ELECTRIC OPERATION

	Total Cost 465,750 Train Miles	Per Train Miles
Power—paid for at power company lines	$47,381	10.18c.
Transformation of power from 88,000 volts a-c. to 3000 volts d-c	8,343	1.79
Engine drivers and assistants	19,024	4.08
Electricians and mechanics (running maintenance)	2,931	0.63
Locomotive wipers	1,640	0.34
Lubricants and miscellaneous material	10,607	2.28
Total	$89,926	19.30c.

From a comparison of Tables III and IV it will be seen that the cost of the electric operation is approximately one third that of steam and that the cost of power for the electric is approximately one fourth that of the cost of coal.

Table V shows the comparison of heavy maintenance of steam and electric based on a year's service of train miles.

TABLE V

REPAIRS AND HEAVY MAINTENANCE

	STEAM		ELECTRIC	
	Total Cost 467,570 Train Miles	Per Train Mile	Total Cost 465,750 Train Miles	Per Train Mile
Labor	$13,512	2.90c.	$6,250	1.34c.
Material	18,303	3.93	3,928	0.84
Total	$31,815	6.83c.	$10,178	2.18c.

The cost of operating and maintaining the 10 miles of high voltage (88,000) transmission line and the 71.4 miles of secondary distribution system for one year of 465,750 train miles is shown in Table VI.

TABLE VI

	10 KILOMETERS OF 80,000-VOLT TRANSMISSION LINE		71.4 MILES SECONDARY DISTRIBUTION SYSTEM	
	Total Cost 465,750 Train Miles	Per Train Mile	Total Cost 465,750 Train Miles	Per Train Mile
Labor	$1,865.00	0.40c.	$4,271.00	0.91c.
Material	272.50	0.06	559.50	0.12
Total	$2,137.50	0.46c.	$4,830.50	1.03c.

For the final total economy of electric service over steam, Table VII shows the total costs on the basis of a year's service or 465,750 train miles.

TABLE VII

	COST PER TRAIN MILE	
	Steam	Electric
Operating trains	63.09c.	19.30c.
Locomotive repairs	6.83	2.18
Transmission line operation and maintenance		0.46
Tolley—ditto		1.03
Total	69.92c.	22.97c.

The last schedule is taken as of July, 1923. During this period passenger traffic had increased materially and also there was a gradual increase in freight traffic. The reduction in the number of freight trains was the result of increased tonnage per train and the more uniform and regular movements of traffic.

It is obvious that great savings will be secured from the decreased train movements and the resulting reduction in the expense of train and engine crews in the freight service. Standby losses will be reduced and better economy will be secured by the use of electric power.

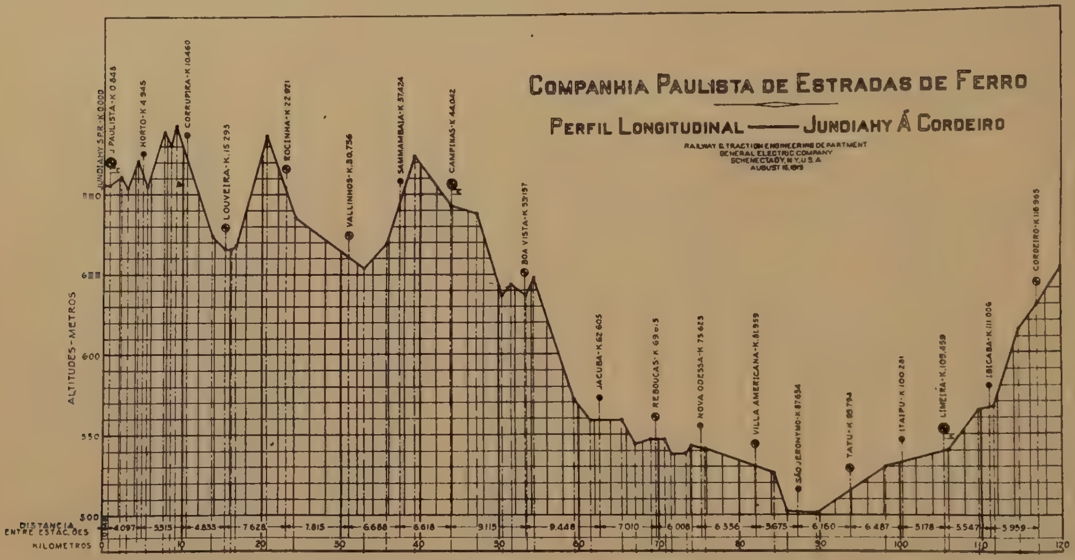

Fig. 5. The profile includes a section 120 kilometers in length for which electrification plans have been made by the Paulista Railway. About two-thirds of this will be electrified when the present extensions are completed to Tatu

The locomotives furnished for this service were equipped with regenerative control and while the grades are not long they reach maximums of 1.8 and 2 per cent and are of sufficient length to return power to the trolley in considerable quantity. A profile of the line is shown in Fig. 5. Train power consumption readings taken at the locomotives show that the average returned to the trolley in passenger and freight service amounts to 13.2 per cent. This includes the total for all switching and handling of locomotives at terminals and engine houses. While these averages show the return at the locomotive it is interesting to note that less than 5 per cent of this energy is returned to the power company's lines, showing that the Railway Company is obtaining almost full benefit from the regeneration since the greater percentage is used direct from the trolley. In addition to this economy there is also the saving on brake shoes and maintenance of braking apparatus which is perhaps the more important of the two. Table I shows the averages of a typical month's service and includes the power consumed at the locomotive in all switching, shunting and standby losses of the locomotives handling through services. Actual yard switching in Campinas and Jundiahy is still handled by steam engines, but equipment for this service has been ordered. The power actually consumed, as measured on the power company's incoming lines, covering the same month as the locomotive values given in Table I, was 796,600 kw-hr.

Table I shows the power consumption and power regenerated at the locomotives for one month's service measured on passenger and freight equipment. All of the locomotives were equipped with standard railway type kilowatt-hour meters excepting two passenger and two freight locomotives and corrections have been made to include their consumption on the basis of their services averaged in proportion to the total averages of the other locomotives equipped with meters.

It is worth while to call attention to the power rates as affecting the Railway Company. For the period from 6 a. m. to 9 p. m., power is paid for at a maximum rate. From

9 p.m. to 6 a.m. the rate is reduced approximately 14 per cent. On Sundays and holidays the maximum rate just given (6 a.m. to 9 p.m.) applies for the full day. Maximum and minimum power demands are specified as well as a load factor between 6 a.m. and 9 p.m.

These restrictions are in keeping with the customs and manner of handling traffic. On Sundays and holidays traffic is cut down so as to include only passenger trains, essential perishable goods trains and stock trains. On National holidays, special effort is made to keep goods trains to the absolute minimum.

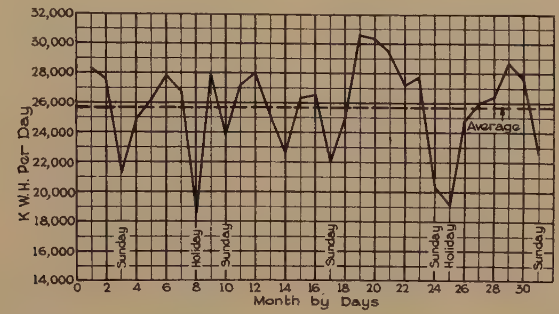

Fig. 6. Chart showing daily power consumption of train on the Paulista Railway for a typical month. It will be noticed in contrast to practice in this country that service is appreciably curtailed on Sundays and holidays

A comparison of power measured at the locomotives to that actually measured on the power company's lines is of special interest, since it shows a ratio of 0.837. This ratio brings out the great economy possible with regeneration and also shows that the regenerated power is taken almost entirely from the trolley giving the railway company the greatest benefit and highest economy.

A typical monthly power consumption curve is shown in Fig. 6. This curve shows the low power consumption on holidays and Sundays in keeping with the manner of handling traffic as mentioned above.

Special tests in freight and passenger service made by the engineers of the railway company, in conjunction with the manufacturer's representatives, show remarkably efficient operation. Results of these tests in both passenger and freight service are given in Table II. The figures given in each case are averages of a sufficient number of trains to eliminate errors and establish accurate data on the performance of their equipment.

As a result of the saving shown by the initial installation, the Paulista Company decided to extend its electrification and in the early part of 1923 orders were placed for the material for electrifying 35 additional route miles of single track. This included 88,000-volt high tension line, secondary distribution, and 3000-kw. substation materials, also five 3000-volt d-c. switching locomotives.

Costs and performance data in this article have largely been taken from the report of Eng. F. de Monlevade, Inspector Geral da Companhia Paulista de Estradas de Ferro in the October, 1923, number of the *Revista Brasileira de Engenharia*.

The costs given on maintenance and operation are based on an exchange of 8$400 equal to $1.00 which is the average exchange over the period for which the costs are given. While the comparison of steam and electric service are exact, the costs in American money are not strictly comparable with services in this country, due to the varying exchange. It is intended to bring out the results and comparison of steam services versus electric more than to compare costs of similar services in this country.

Some Bearing Investigations

By E. G. Gilson

Research Laboratory, General Electric Company

In the operation of bearings there have always been met a number of puzzling phenomena, which have too often led to limitations in the design of machines. The author writes a most interesting and valuable account of the original work recently done in studying these phenomena. The results obtained are as strikingly new as the methods adopted for their determination.—Editor.

In the demand for higher speed and greater output from a given machine, the point has been reached where the limitations of our present bearings must be overcome or the further progress of machine design will be greatly jeopardized. With this idea in mind, the Research Laboratory started some investigations in bearing phenomena, the preliminary results of which are briefly described below.

When bearing troubles occur, it is usually said to be due to poor bearing material, or failure of lubrication. As a result of this condition, we have bearing materials ranging from rubber, soft babbitts, etc., to hard bronzes, hardened steel, and even sapphires and diamonds. Also we have available many different kinds of oil as lubricants.

But while all this has resulted from the effort to improve bearings, failures are not fully explained yet. To find a cause which could be definitely connected with these failures, these experiments were undertaken.

As the common indication of impending trouble is a rise of temperature, usually attributed to an overload, the first investigations were on the behavior of bearing metals under load. For this purpose special test stands were built. These stands consisted of a belt driven shaft carrying a replaceable collar about 3¾ inches in diameter by 3 inches long, to represent the journal material. The bearing material under observation, in the form of a block, was held against the surface of this collar as it revolved, pressure being applied by means of compound levers. Lubrication was supplied by a wick feed from an oil receptacle in which the oil was kept at a constant level.

The results were of very doubtful value. For instance, with an ordinary bearing material, which is limited in practice to loads of 65 to 100 lb. per sq. in., a load of 5000 lb. per sq. in. could be carried at rubbing speeds of 550 ft. per min., without the slightest signs of distress. While this speed is not high, corresponding to about 1000 r.p.m. on a 2 inch shaft, the pressure is far beyond anything attempted in practice.

A study of the friction of bearing materials soon showed that there was little to be gained along that line. Tests made on a standard type friction testing machine proved to be very erratic, even though great care was used in preparing the surfaces, and in maintaining other conditions. Even with the same test block, and all conditions apparently the same, different results would be obtained from day to day. An example of what would happen is shown in Fig. 1. Here are three curves showing the coefficient of friction of the same test block taken on three different days. All the conditions are identical, excepting the single one of room temperature. With the room temperature at 24½ deg. C. we get the lower curve. With the room temperature at 16 to 17 deg. we get the upper curve, while with the room temperature at 21 deg. we get the curve lying between the other two. Similar results are obtained by running the test machine continuously, the friction and consequent temperature rise going down as the room temperature goes up, or, going up as the room temperature goes down.

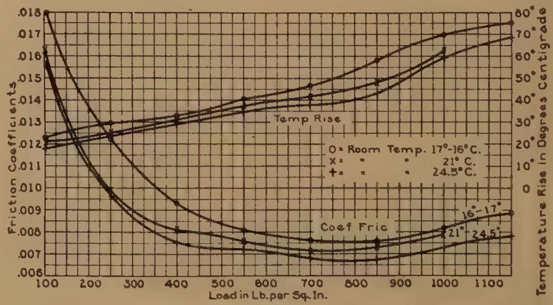

Fig. 1. Change in Friction with Change in Room Temperature

Ordinarily variations in room temperature are considered immaterial in a test of this kind, the criterion being the temperature rise, but we see here that the room temperature is a factor, the friction and consequent temperature rise varying inversely with the room temperature.

A very significant fact is that although the temperature rise is different for the three curves, the ultimate temperature in each case is practically the same. This would seem to indicate that temperature rise does not tell the whole story, particularly when the friction surfaces are in contact with relatively large masses of metal as is the case with this particular type of testing machine.

As the above results did not seem to lead to anything definite, a small bearing 1 inch in diameter by 3 inches long was run for observation at a fairly high speed, about 14,000 r.p.m., or about 3700 ft. per min. rubbing speed. This was a plain cylindrical bearing of babbitt, with a steel shaft having a clearance (dif. in diam.) of about 0.002 inches. Oil was supplied in a steady stream, fresh oil only being used. There was no load on the bearing excepting the belt pull. In a very short time the bearing was so hot the run had to be stopped. Its condition after this run is shown in Fig. 2, which shows the bearing split on its horizontal diameter. The oil distributing groove was on top and the belt pull was against the side having the hole in the edge. It can be seen that the babbitt is badly "flowed." The most interesting thing, perhaps, is that the "flow" appears to be the greatest on that side opposite to which the shaft is drawn by the belt pull. The shaft showed signs of having been hot but otherwise was in good condition. There was no cutting or freezing. Here was a good bearing material, a good shaft, ample clearance, flooded with oil, no load on the bearing, but the result is a bearing failure. It looked, therefore, as though the trouble must be elsewhere than the metals of bearing and shaft, the most obvious place for it being perhaps the internal friction of the oil at the high speed. Still, in this experiment, we had the possibility of rubbing metal due to the belt pull.

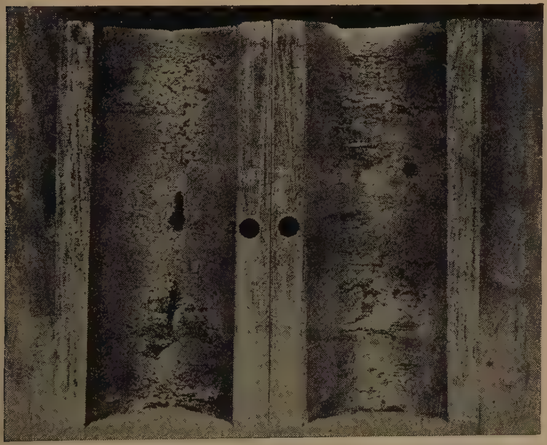

Fig. 2. Typical Failure of Well-oiled Babbitt Bearing Due to Speed

So next a machine was devised in which the rotating and stationary elements could be positively held apart, speed controlled as desired, and an oil film maintained between the moving and stationary surfaces. Any effect noted must then be due to shearing of this film, or to internal friction of the oil. A thermo-couple projecting into the film indicated the temperature. The results with this crude device were surprising. The effect of the speed on the temperature of the oil is shown in Fig. 3. The conditions on these three runs were all the same excepting the speed; in run No. 1 it was 8350 surface feet per min.; run No. 2 it was 11,000 surface feet per min.; and run No. 3 it was 8990 surface feet per min. The sharp rise at the end of run No. 1 was due to raising the speed from 8350 to 10,270. The clearance given (0.015 inches) means thickness of oil film; in other words, the difference in diameters was 0.030 inches. None of these runs was carried to a conclusion because of breakdowns of the apparatus, due to failure to realize the load conditions. These curves were taken with a babbitt ring and a shafting steel bowl. The heat developed was so great that it raised the question whether some of our bearing failures, which occur for no apparent reason, could not be explained wholly by the heat of internal friction of the oil film. If this was so, there should be no trouble in melting out a ring in this machine. This we found we could do easily and in Fig. 4 is shown a ring on which this has been done. The surface has softened to such an extent that it washed away but the run was stopped before the ring was completely melted down. The hole is where the thermo-couple projected. Fig. 5 shows the same thing to a

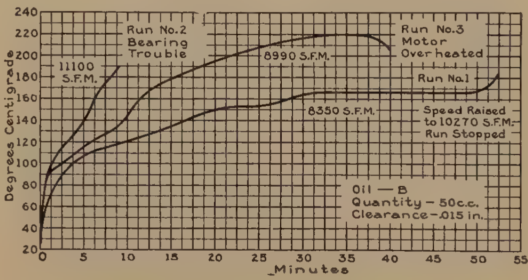

Fig. 3. Effect of Speed on the Internal Friction of an Oil Film as Indicated by the Temperature

lesser extent. As an oil film approximately 0.015 inches was maintained at all times these effects must be due wholly to the heat developed by the internal friction of this oil film.

This machine gave such unusual and marked results, principally on the oil, that it was developed to its present state and a large amount of work has been done with it. Its present form is shown diagrammatically in Fig. 6. The bowl, or rotor, "B" is made of shafting steel; the ring "R" is made of the bearing metal under investigation. This ring is supported on the shaft by the light steel spider "S." The shaft, in turn, is locked inside the quill "Q," which is supported by the ball bearings, and the torque reaction of the ring is balanced by the helical spring surrounding the quill. The deflection of the spring, due to the torque, is indicated by the pointer "P" moving over the scale "C." The shaft is hollow and the leads of a thermocouple are brought out through it, the couple itself being supported in the ring by means of a fiber plug so that it projects into the oil film. Photographs of the actual parts are shown in Fig. 7 and of the machine assembled ready to run in Fig. 8.

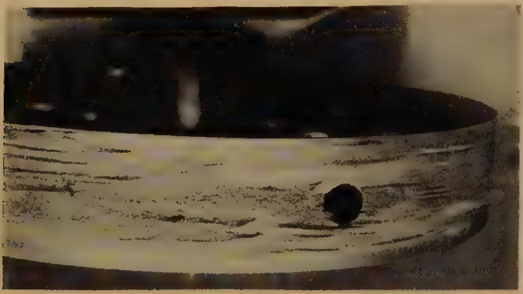
Fig. 4. Babbitt Ring Melted by the Internal Friction of the Oil Film

Fig. 5. Same as Fig. 4, but not carried quite as far

In operation a fixed charge of oil is put in the bowl and the machine assembled and started up. The centrifugal force immediately throws the oil against the vertical wall of the bowl. Enough oil is used to make a film theoretically about twice the thickness of the clearance space between rotor and ring when it is all against the vertical wall of the rotor. Observation shows that the oil is rapidly circulating when in operation. It comes out through the top of the clearance space, not as a solid film, but boiling and frothing violently, falls down inside the ring to the bottom of the rapidly revolving bowl where it is immediately thrown again to the vertical wall and then starts through another cycle.

A series of runs were made using 8 different oils and 10 different rings and bearing metals. The metals used were a babbitt, a bronze, copper, genelite, aluminum, tin, lead, antimony, steel and zinc. The oils used were four petroleum lubricating oils, one petroleum oil purified for medicinal purposes, castor oil, sperm oil and lard oil. Each oil was run with each metal ring using a constant speed of 8000 surface feet per min.; a constant thick-

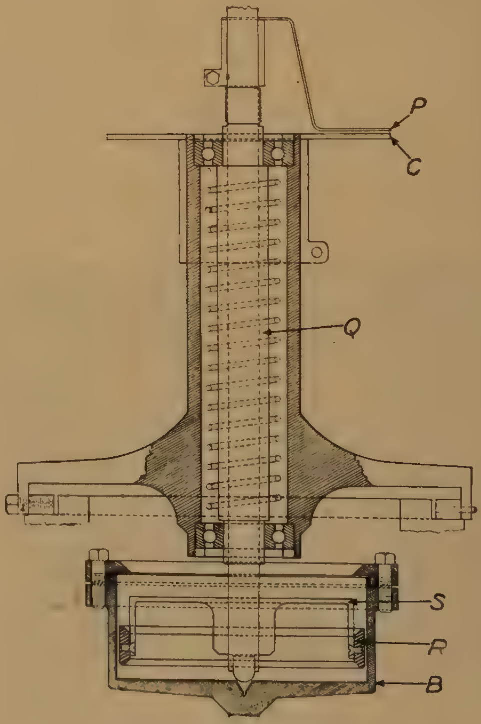

Fig. 6. Diagrammatic Sketch of High-speed Internal Friction Oil Testing Machine

ness of oil film of 0.013 in. and the same shafting steel bowl in all cases. The clearance, or thickness of oil film, was measured at ordinary room temperature and no attempt made to compensate for expansion due to heat.

In the extreme case the vegetable and animal oils become completely solidified. It is necessary to dig them out of the bowl while still hot, as on cooling off they become a solid mass much resembling rubber. A mineral oil becomes very black and viscous with a large percentage of solid matter, or sludge, settling out. In these extreme cases a wheel of high melting point must be used on account of the heat developed. All this occurs in a comparatively short time. The standard length of run was 90 min. but many had to be stopped in shorter time on account of the heat developed.

It soon became apparent that the results obtained depended entirely upon conditions. For instance, changing the ring but using the same oil and maintaining all other conditions the same would change the results. Or, changing the oil, but using the same ring with all other conditions remaining the same would also change the results. This is well shown in Figs. 9, 10, 11, and 12. These are the temperature and friction (or power absorption) curves of the two mineral oils which we will call "B" and "W." These are both light oils of a high grade especially designed for high speed spindle work. Fig. 9 shows the results with a bronze wheel. The curves for the "W" oil lie well above those of the "B" oil. It is also quite noticeable that, while the "B" oil apparently comes to an equilibrium and runs along uniformly for the 90 minutes of the run, something has happened to the "W" oil after about 45 minutes of the run, for, at that point, temperature and power absorption curves start to rise quite rapidly.

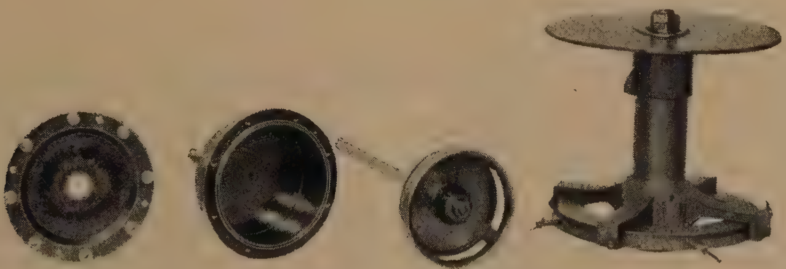

Fig. 7. Principal Parts of the Machine Sketched in Fig. 6

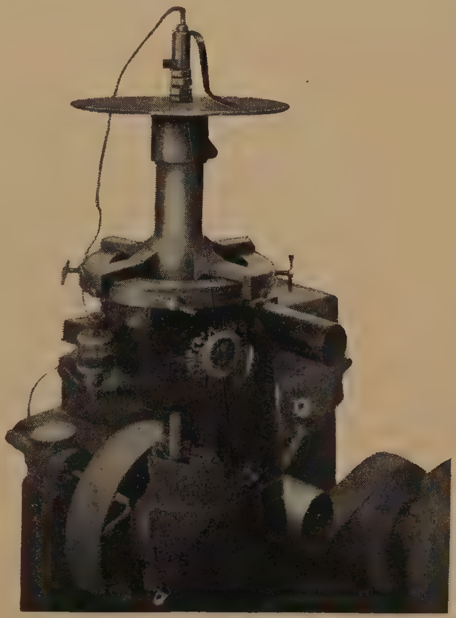

Fig. 8. High-speed Internal Friction Oil Testing Machine Assembled Ready for a Run

Fig. 10 shows the results of using "B" oil and replacing the bronze ring with one made of copper. This gives a pretty close check. Fig. 11 shows a comparison of the curves of the "W" oil with bronze and with copper rings. Here the curve for the copper ring, instead of checking with that of the bronze ring, lies well below it. Fig. 12 shows a comparison of the results of the "B" oil with the bronze and the "W" oil with the copper. On this there is a pretty close agreement. In other words, from the standpoint of the internal friction of the oil (and that is what must be given more serious consideration in high speed bearings in the future) it looks as if one should change from a bronze to a copper bearing when changing from "B" oil to "W" oil, if the best results are to be obtained. It also shows, conclusively, that although the metals do not come together, but are separated by an oil film (in this case of very appreciable thickness) it does make a difference what the metals are.

This is not an isolated case but is in evidence all through the work. These particular curves were chosen because the oils are apparently very much alike, and the metals are, in one case, copper, and in the other (although an alloy) one that is very high in copper.

Another very marked example of the effect of the different conditions upon the results is shown in Fig. 13. These are the curves produced by using castor, lard and sperm oils with a copper wheel. Although these oils are good lubricants, the power absorption and temperature are much higher than is shown with the petroleum oils in Figs. 9, 10, 11, and 12. But the most peculiar feature is the very sharp drop in the friction curves and the consequent drop in the temperature curves just before the abrupt rise which indicates the end of the run. The rise in the curve is almost vertical and probably indicates a conversion of the oil from a liquid to an approximately solid mass. Immediately preceding this change the oil is, apparently, at its lowest viscosity. This thing occurs at about the same spot, as measured by time, in all three oils. The same phenomenom occurs when an antimony ring is used, as can be seen by referring to Fig. 14, but it does not appear with any of the other rings above mentioned. With the others there is not the sudden dip in the curves and the rise is of a more gradual nature.

A very interesting point in these experiments is the pressure built up in the film. In the early experiments a manometer connection was made to the oil film through a small hole in the ring. (This hole can be seen in Fig. 5). Although this connection was on the inside of the circle where the centrifugal forces would oppose the building up of pressure, the manometer would register, at times, pressure as high as 6 to 8 in. of mercury.

After the runs some of the rings exhibited very peculiar surface conditions; lead, for

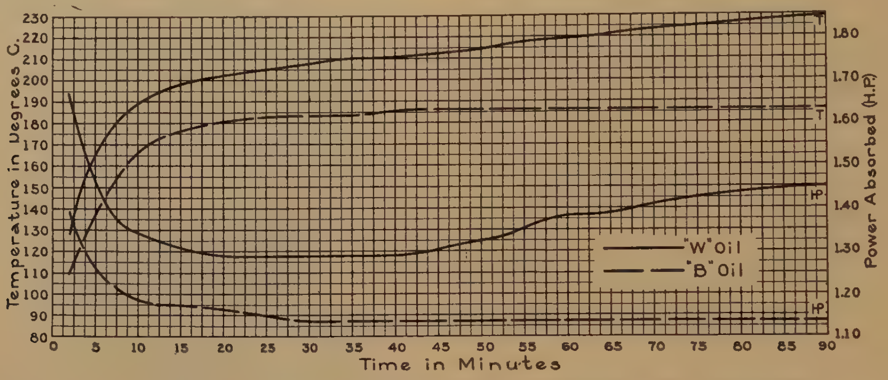

Fig. 9. Friction and Temperature Curves of "W" and "B" Oils Run with a Bronze Ring

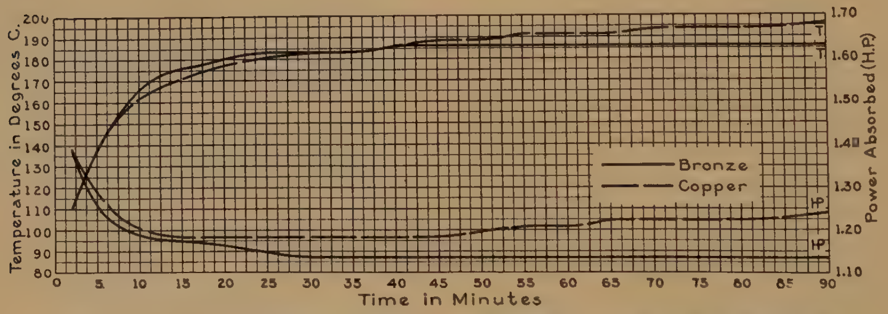

Fig. 10. Friction and Temperature Curves of "B" Oil Run with Bronze and Copper Rings

instance, had a decidedly etched effect, the crystal structure standing out very clearly. Copper, in some instances, was badly discolored. Babbitt, bronze and steel were very considerably pitted. This pitting can be seen clearly in Figs. 15 (Babbitt), 16 (Bronze), 17 (Steel).

The oil from these experiments always came out very badly broken down, worn out, or burned up (as it is commonly called). If the sludge from these oils was allowed to settle and the soluble oil washed out of it with benzol, the solid matter resulting was found to be not at all of a lubricating nature. In some cases it approached more nearly an abrasive. This sludging was probably due to oxidation, although with some oils it took place even when oxygen was apparently excluded. But the interesting point in this connection is that this act of oxidation (or sludging) is apparently necessary for lubrication. For, when it is prevented by running in an atmosphere of hydrogen (for instance), the internal friction is invariably much higher and remains so as long as oxygen is excluded. But, when, at any time the hydrogen is turned off and air admitted, the friction falls to its normal value. The same thing occurs even with those oils that sludge in an atmosphere of hydrogen, so that it would look as though oxygen was a necessary factor in keeping the internal friction low. At the same time, it must not be overlooked that, as the sludge begins to gather in quantity, the friction goes up, so that, probably, it is the reaction of forming the sludge and not the product itself that is the important factor. In other words, it appears as if the act of lubrication is simply the act of oxidizing the oil.

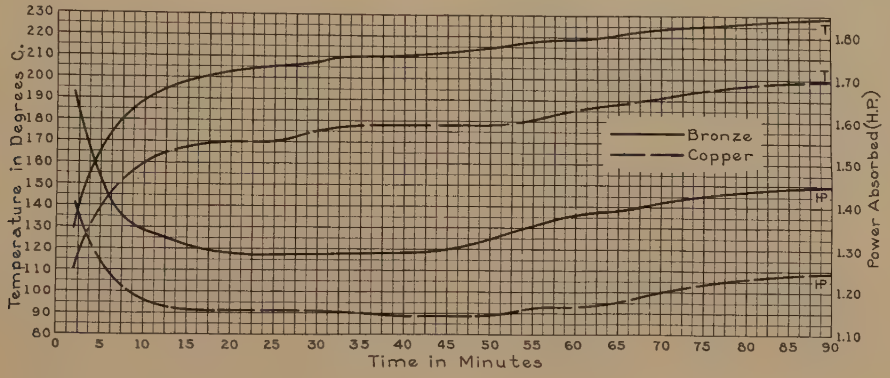

Fig. 11. Friction and Temperature Curves of "W" Oil Run with Bronze and Copper Rings

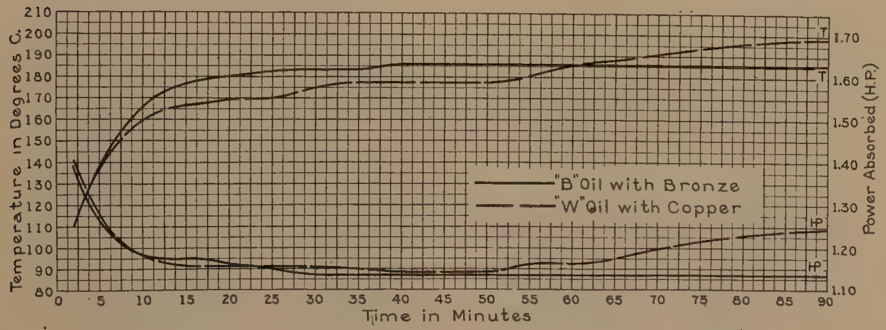

Fig. 12. Friction and Temperature Curves of "B" Oil Run with Bronze Ring and "W" Oil Run with Copper Ring

These experiments created a desire to know more about the performance of an oil film in an actual bearing. As a means of studying this a bushing about 2 inches inside diameter by 2¾ inches long was made of glass. This was held by brackets on the end and the arrangement was such that it could be secured in any position desired in relation to the journal. Most of the work was done with bearing and journal concentric. This glass bushing was ground true and smooth on the inside. The clearance (difference in diameters) was about 0.003 inches.

The first method of supplying oil was with a squirt can through a ⅛-inch diameter hole placed in the top of the bearing midway of its length. Contrary to expectations the oil would not flow through this hole into the bearing. Only enough would enter to make a band of oil about ½ inch wide around the bearing, the rest of the oil running down over the outside and dripping off, i. e., the oil would not spread through the bearing regardless of the time given to do it. A connection was then made to this hole so that the oil could be supplied under a static head of about 10 inches. With this arrangement the oil would spread through the bearing and flow out at the ends. Cavitation, however, was very marked and could only be overcome by using a very large quantity of oil, something like a pint in 5 minutes.

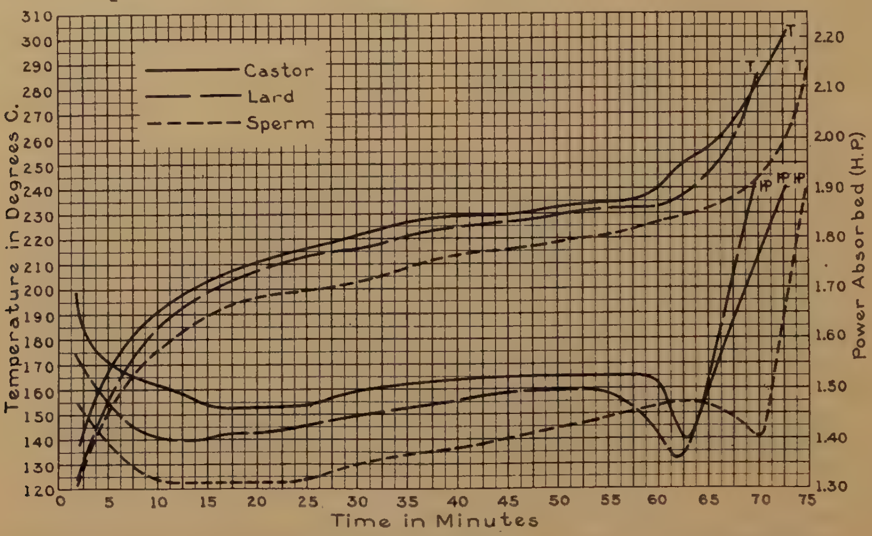

Fig. 13. Peculiar Dip in Friction and Temperature Curves of Castor, Lard, and Sperm Oils When Run with Copper Rings

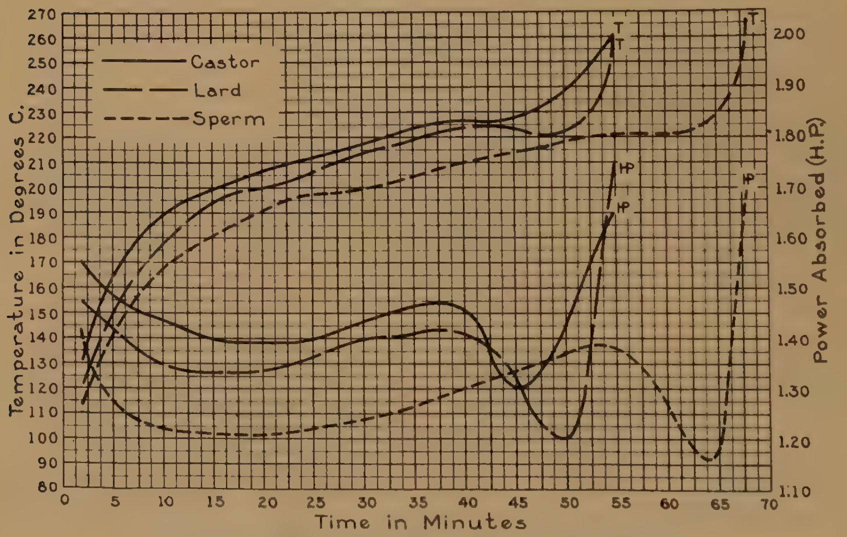

Fig. 14. Same as Fig. 13, except that an Antimony Ring was used

Next an oil ring slot was cut in the bushing in place of the oil hole. With this arrangement it was found practically impossible to get any oil to flow through the bearing although the ring was carrying up plenty of oil all the time. The best results were obtained when a very thin oil was used. In this case the oil would spread to approximately ½ inch each side of the oil ring slot, but none would come through and out at the ends of the bearing although it was left running as long as 8 hours at a time. With a heavier oil (something like a light machine oil) the spreading would not be more than ⅛ to $\frac{3}{16}$ of an inch each side of the slot.

Straight oil distributing grooves were then cut on the inside of the bushing, one at each end of the oil ring slot, and extending parallel to its axis to within about $\frac{3}{16}$ inch of each end of the bushing. The oil would now spread out to the end of these grooves, but only a very small amount would go beyond the grooves and come out at the ends of the bearing. With this arrangement, cavitation was very marked, showing up as decided streaks when the shaft was turning, and immediately forming into gas bubbles when the shaft stopped.

With the desire to get more oil to flow through this bearing, short spiral grooves were cut in from each end overlapping the straight grooves, above referred to, about ½ inch. The spiralling was such that the direction of rotation would tend to cause the oil to flow out. Contrary to expectations, these spiral grooves had not the slightest effect on the flow of oil.

Fig. 15. Photomicrograph of Babbitt Wheel (x 75). Condition of surface after run

The original idea of this glass bearing was to study the action of the oil film at high speeds. But the heat developed was so great (although it all came from shearing the oil film as there were no parts rubbing), that the foregoing experiments were all made at 1000 r.p.m., or less, for fear of breaking the glass.

These experiments were so interesting that a more complete apparatus was made for this study. This piece of apparatus is shown in Fig. 18. The size of the bearing is 2 inches diameter by 5 inches long. The glass is accurately ground to a smooth surface on the inside, grooved as desired, and mounted in brass cages as shown at the extreme right of the picture. When the bearing is mounted on the journal, the load is applied by means of the weight at the end of the long lever. With this weight removed, the bearing is practically balanced so that it probably floats concentric with the journal. Torque reaction is taken

Fig. 16. Bronze (x 40). Condition of surface after run

Fig. 17. Steel (x 40). Condition of surface after run

by means of the link connecting the top bar of the bearing cage to the small bell crank lever. The amount of this torque may be measured by sliding the small weight on this lever until a balance is obtained.

It was found to be almost impossible to get rid of cavitation entirely but the type of grooving used had a great influence on this. Fig. 19 shows the cavitation in a bearing having straight oil grooves running at 1000 r. p. m. with a load of 8 lb. per sq. in. Fig. 20 shows the same bearing immediately after stopping. In Fig. 19 the cavitation is shown by the circumferential streaks which are the gas pockets drawn out by the motion of the journal. Fig. 20 shows these resolving themselves into bubbles again upon coming to rest.

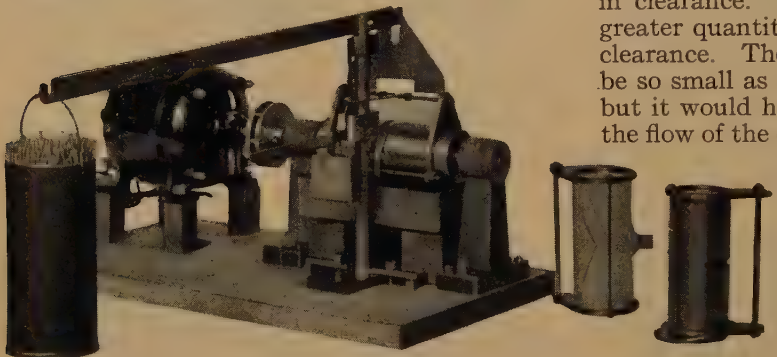

Fig. 18. Test Stand Used with Glass Bearings

Incidentally, there was probably a good deal of pressure built up inside these bearings, for a great many of them broke, and the trouble was always apparently caused by pressure from the inside. This was relieved quite materially by binding with string as shown in the pictures.

Some measurements of torque and temperature rise were made with interesting results. As stated above, the cavitation could be controlled to a large extent by the type of oil grooving used, but the more nearly perfect the oil film was maintained the greater the torque but the less the temperature rise. For instance, in one case, with a torque of 3 inch-pounds, the temperature rise was 33 deg. C., while with a different type of grooving, under conditions otherwise the same, the torque was 4 inch-pounds while the temperature rise was only 21 deg. C. This is in accord with the work described above on the internal friction of an oil film.

While taking these torque measurements it was very evident that there was more oil flowing through the bearing that showed the greater torque. Consequently, measurements of the actual amount of flow were made, and it was found that over 3½ times as much oil was flowing through this bearing as was flowing through the other. The first bearing had 7.95 grams of oil per min. passing through it while the second bearing was passing 29.93 grams. The excess oil was running over the outside and dripping off the bottom.

While investigating the flow of oil through quite a large number of these bearings, it was noticed that the flow from both ends of a bearing was seldom anywhere near the same. This was very puzzling for a while as no type of grooving seemed to influence this condition. Finally, after careful measurements, it was determined that this was caused by differences in clearance. The oil would always flow in greater quantity to the end having the larger clearance. The difference in clearance might be so small as to be very difficult to measure but it would have a tremendous influence on the flow of the oil. If it amounted to as much as 0.001 inch practically no oil would flow to the small end.

From the standpoint of flow of oil to the bearings, which now seemed to be a very desirable feature, grooving the bearing did not seem to be very efficient, as only a small percentage of the oil carried up by the ring would go through the bearing. Most of it would simply run down over the outside and drip off.

Therefore, grooving the shaft was tried instead. With a properly designed grooved shaft, it was found that any amount of oil that could be brought to it by the ring could be carried through the bearing. The limiting feature was now found to be the ring. Investigation of this showed that, at the speed of the experiments (1000 r.p.m. and less) the rate of oil flow was directly proportional to the width of the ring. At greater speeds than 1000 r.p.m. the ring became inefficient, centrifugal force becoming a large factor by causing a large percentage of the oil to fly off. This, of course, becomes worse as the speed increases.

It seems evident from these experiments that the heat of a bearing is mostly generated by the internal friction of the oil film. The metals are, however, a large contributing factor due to their effect on the internal friction of the oil. Consequently, a bearing should always be considered with due regard to the effect that any one of its three chief component parts may have when used with the other two. Of these parts the journal may be considered more or less fixed, but the bearing material and the oil may be changed at any time and there is a great variety of both to choose from. For best results at high speed these, probably, should be rigidly controlled by specification.

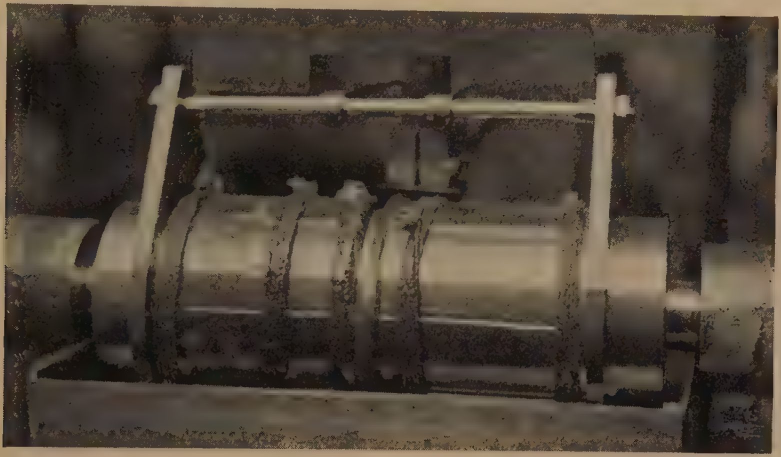

Fig. 19. Cavitation Shown in a 2 by 5-in. Bearing Running at 1000 R.P.M. Under Load of 8 Lb. Per Sq. In.

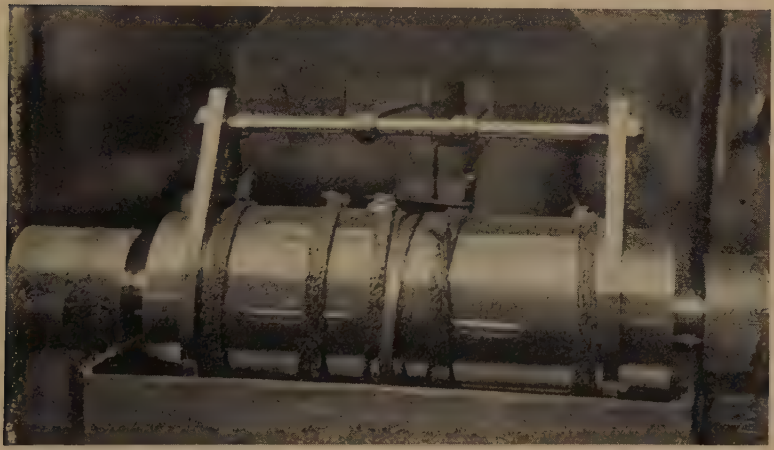

Fig. 20. Gas Pockets (Cavitation) Shown in the Bearing of Fig. 19 Immediately After it Has Come to Rest

While it appears that the act of breaking down, or sludging, of the oil is necessary to lubrication, the final product of the breakdown, or sludge, is harmful. This effect on the oil should, therefore, be controlled. It is influenced by the temperature to which the oil is subjected, increasing with great rapidity with increase in temperature. Hence it would seem that the obvious road to improvement of our bearings is to consider them as simply heat generators, and to design them with the object in view of removing this heat in the most efficient manner possible.

In this work no attempt has been made to study the effects of pressure on the temperature of the oil film, neither has any work been done on the effect of the thickness of the oil film on the heat generated, other than a few preliminary experiments, showing that the temperature rises very rapidly as the thickness of the film is diminished. Both of these conditions offer a large field for investigation and, when we fully understand the laws controlling them, we should be able to increase our bearing speeds and loads very greatly, and with absolute safety.

Mechanical Strength in Its Relation to Absolute Size

An Engineer's After-dinner Dream on Mechanical Constructions, Insects, Babylonians, the Earth, Einstein's Theory, Bronto-saurians, the Absolute Unit System, Mountains and other things.

By H. E. EISENMENGER
THE NEW YORK EDISON COMPANY

The author in an interesting and novel way shows why mechanical strength and other quantities are dependent on absolute size and not on relative size. He covers such a wide range of subjects in making his point clear that most engineers will get much pleasure, as well as profit, in reading his treatment.—EDITOR.

Motto: Vive, vale, si quid novisti rectius istis
Candidus imperti, si non, his utere mecum.
—(*Horace*).

Probably most thinking engineers—and an engineer who does not do his own thinking is no engineer—have wondered some time or other why it is that we cannot enlarge a given piece of engineering construction without impairing its strength. If we wish to enlarge it beyond a certain measure we have to materially change the way it is built. If we have a railway bridge with a span of 30 feet, built according to best practice, and would want to build another one exactly like it, but 100 times as long, 100 times as wide and 100 times as high, with every part being 100 times as large in every dimension as the original part—provided it were possible to manufacture and install all these parts at that size—that new bridge would break down under its own weight and under the wind pressure before it was in a position to carry any useful load. A ship of 50,000 tons must be constructed altogether differently from a 500-ton ship, a 5000-h.p. electric motor is by no means the enlarged replica of a 5-h.p. motor, the enlargement of an ordinary wheel to hundred times its size leads to the thoroughly calculated and intricate construction of the Chicago Ferris Wheel, etc.

In Nature herself the same phenomenon is to be observed. It is no mere accidental happening that there are no insects in existence larger than a very few inches at the utmost. The construction of their bodies with its outer chitin skeleton as supporting structure, if proportionately enlarged, would not be able to bear a much larger body. The smallest insect, however, is a giant as compared with the members of the world of bacteria. On the other hand, mammals and other vertebrates are fundamentally different in construction from both insects and bacteria and they are of a size many times that of the insects. But here too is an upper limit: the gigantic land mammals of former times as well as the enormous saurians and other giants have not been able to hold their own. Even the largest mammals of the present age, the whale, or the pachyderms such as the elephant, the hippopotamus and the rhinoceros seem to be doomed to follow into extinction the moa of New Zealand and other vertebrate giants. It appears that these animals have reached or exceeded the limit of the size which is practicable for their construction.

Enlarging a certain structure proportionately in every dimension means weakening it; reducing it, means strengthening it. A little superficial mathematics demonstrates *that* this is so but does not explain *why* it is so. To take a simple example:

A large ball of lead is suspended from a wire. Enlarging this combination ten times in every dimension will make the weight of the ball 1000 times as great, whereas the cross section of the wire increases only 100 times; therefore the tensile stress on the wire per square inch of its cross section is 10 times as great as before. Similar computations apply to bending stresses, etc.

This gives all the explanation the engineer needs for his practical work at his desk, but in his after-dinner dreams he may well wonder what is that strange thing that ties the possibility of using a certain type of construction, to a certain definite size. If I change the size proportionately in every dimension, what else am I changing relatively thereby, so that the strength of the whole thing is so much reduced or increased?

There is no absolute standard of size, all size is relative, all space dimensions are relative. Why then can we not construct in our imagination a Lilliput or a Brobdingnag world with nothing changed but the size of everything? It would seem at first sight that shrinking ourselves and everything around us to, say, 1/10,000 in each linear dimension and leaving the material unchanged of which everything is made would make the whole change unnoticeable to us as all our standards of size, our scales, our inches, etc., would shrink with us. Yet we would be in a strange and unaccustomed world. Not only would everything be so much stronger mechanically, but we could also, for example, throw ourselves from the top of our highest skyscraper and arrive at the bottom unhurt in a fraction of a second. What is now for us a light breeze would be in our imagined Lilliput world a terrific hurricane, even though the air velocity is proportionately reduced; at least it would sweep our tiny bodies—specks of dust as they would be—off our feet and hurl, or rather float, us through the air, without, however, doing us any damage. We are accustomed to have a pendulum oscillate in one second if it has a length of about 40 inches, that is roughly one half of our own height. In our miniature world each oscillation of a pendulum of half our own length would take only 1/100 second, and since the frictional dampening limits the number of oscillations to a certain amount the pendulum would be at rest immediately after it had been started swinging. It would be easy to give numerous examples showing that the proportionate reduction (or increase) of every dimension in ourselves and our entire surroundings would not only change the mechanical strength of everything but would make an entirely different world for us.

The first thought that offers itself as an explanation for this is that we have not reduced or enlarged the dimensions of everything in the same measure. The earth as the source of the gravitational attraction has been left unchanged in size.

Suppose we have a bridge and enlarge its every part in every dimension ten times. Before the change, its length was $\frac{1}{n}$ of the diameter of the earth, after the change it is only $\frac{10}{n}$. If we reduce the same bridge 10 times in size its length is only $\frac{1}{10n}$ of the diameter of the earth.

Let us then imagine that we could have a replica of the earth and of everything on and in it (and of the universe as well, for that matter)—except that it is for instance 10,000 times as small in every dimension, but made of the same material throughout in every particle as our real earth. We would then have a globe floating in space, practically outside of the influence of gravitation from the outside world, with a diameter of a little more than 4000 feet. The distance from New York to Europe on this globe would be a little over 2000 feet, the length of Manhattan Island would be about seven feet. On this the highest skyscrapers would tower about one inch in height whereas an ordinary residential house would be about the size of a poppy seed or a hemp seed. The very highest mountain peaks in the Himalayas on that miniature globe would be three feet in height above sea level and the ocean would be only a few inches in depth in most places, with a few rifts or clefts reaching to about 3 feet.

If we stood in our natural unreduced size on the surface of this miniature earth, overtopping the highest mountains, with the clouds floating somewhere around our knees, we would feel our weight reduced to a fraction of an ounce. But—always under the assumption that conditions could be entirely the same as on our real earth except proportionately reduced throughout in scale—we would find breathing impossible because our head would stick out of the atmosphere. This and all the other hardships of an extremely rarified atmosphere would induce us to lie down into the strata where the air pressure is nearer to what we are accustomed. We would then find ourselves floating horizontally in the air and our downward motion from gravity would be so extremely slow as to be imperceptible for quite a while.

What on the other hand would happen on our original earth to a man of corresponding size who is almost as tall as Manhattan Island (13 miles) or twice as tall as our highest mountain peaks? The bones of this giant would probably break under his enormous weight and we would see a mountain of bloody crushed flesh squeezed by its own weight under a pressure that can be paralleled only by some of our most powerful hydraulic presses.

If one of the miniature men would fall from the top of one of the miniature skyscrapers, he would land on the pavement below with a speed of a little more than ¼ inch per second after having fallen for about eight seconds. The effect of such a fall will therefore be entirely different from what it is on our earth.

The atmosphere on this model of an earth globe would not be—as assumed heretofore—only a few feet high. In order to reach the same pressure at sea level as on our earth the height of the atmosphere would have to be 10,000 times as high as on our earth absolutely or in relation to the diameter of the globe 100,000,000 times as high.

These few examples show that proportionately changing the dimensions of everything surrounding us, even including the earth itself, would leave conditions by no means unchanged but would result in entirely different surroundings.

Since a uniform reduction in space does not leave things relatively unchanged, we must conclude that there seems to be some unchangeable absolute size to which every size is referred and which is not reduced in our above proposition. By reducing everything uniformly in size the relation of all sizes to that unchangeable standard of size would change, just as we have had a partial explanation for the change of conditions where we leave the size of the earth unchanged as a standard size, as it were. Or there might be some other element which is not touched by a reduction of the sizes. Or there might be a combination of these two causes.

Before investigating this point, however, a few words of explanation on another point of the problem will be inserted here.

It must not be imagined that our aim in this investigation is—or can be—the construction of an imaginary universe in which not only the linear dimensions would be reduced to 1/10,000—or whatever the ratio is—but everything else capable of measuring would also be reduced in the same ratio, such as acceleration, force, energy, power, etc. This would be neither what we want, nor would it be possible of attainment, as can be best demonstrated by a few examples as follows:

If we reduce every length to, let us say, 1/10, it is clear that it is neither possible, nor required for our purpose, that every area is reduced likewise to 1/10. The areas will be reduced to 1/100, the volumes to 1/1000. But the individual person having shrunk to 1/10 of his linear dimensions would find that the surface of his body for instance would also have shrunk, not to 1/10 but to 1/100 just as all other areas. That person would therefore not notice any change in the areas although they did not change in the ratio 1/10. The reduced area will have the same number of reduced square feet as the original area contains original square feet. Likewise velocity, acceleration, force, energy, power, etc. may, for all we know so far, change in the same ratio as the linear space dimension or in some other numerical ratio unknown as yet. The crucial point is that the aspect of the universe, the effect, the doings of everything in the miniature world remain unchanged so that the observer, reduced in size, as he is, has no means to notice that any change has taken place.

We return now to our main question why conditions are different in a world differing from ours only in size. Here is where the Einstein theory comes in or rather Minkowsky's time-space theory which has become more widely known to the general public only through Einstein's relativity theory. In the middle of the last century Minkowsky propounded at Cologne his theory of the time-space continuum which states that time and space are quantities of the same order. They are, as it were, manifestations of the same thing; time is, mathematically speaking, a space dimension in an imaginary direction. To locate a certain thing we must not only know where it is in relation to other objects but also when it is there. One object may be separated from the other by a certain distance in space or by a certain distance in time (or both). This leads to the idea in our present problem that it is not enough to proportionately increase (or reduce) the space dimensions but the time dimension must be changed in the same proportion. As long as we change the space dimensions only we can not get conditions similar to those before the change, just as a proportional change of the length and width only of an object without changing the height would obviously not result in a true image of the original object, but in its caricature. The Einstein theory teaches that time may be changed. Time elapses more or less rapidly according to the speed of relative motion. A second on one body may be longer or shorter on another one.

The Einstein theory also shows that there is one unchanged and unchangeable quantity in nature which is somehow firmly established and that is the velocity of light. Velocities are relative, but not so the velocity of light which is, so to speak, the infinite velocity, inasmuch as by adding any finite velocity to itself again and again often enough, we can approach the velocity of light more closely than can be expressed by any finite figure but we will never reach it, not to speak of exceeding it. Velocities add to each other not algebraically but according to a more complicated law. The velocity of light is the standard unchangeable measure of velocity. We can assume an earth 10,000 times smaller than this earth of ours, but we can not, without overstepping the limits of possibility, imagine a velocity of light (in empty space) either greater or smaller from what it is in our world—300,000 km. per second. A ray of light would spin around the equator of our earth 7½ times in one second, and in our assumed miniature earth we will have to choose conditions in such a way that light travels 7½ times around the circumference of our hypothetical globe in one of the new seconds unless we distort the image of the earth by the reduction. Just as one foot on our earth is represented by 1/10,000 foot on our miniature model, so one second of time will have to be represented by 1/10,000 of a second, then the velocity of light (or any other velocity, for that matter) will be unchanged on our miniature globe, because velocity is the quotient of length divided by time.

Physicists and engineers are accustomed to three fundamental quantities in measuring, from which the others can be derived. These fundamental quantities on which the so-called centimeter-gram-second system (c-g-s system) is based are length l, mass m and time t.

The system of absolute units—which has been devised in the 18th and 19th centuries and in part goes back to units devised three or four thousand years ago—is based on three fundamental units which have been arbitrarily assumed: the centimeter which is based on the length which the circumference of the earth happens to have at present; the gram which is based on the centimeter and on the density of water at a certain temperature; and the second, a unit conceived by the Babylonians, which is based on the angular velocity which the earth happens to have at present in its revolution around its axis.

It seems possible that if the system of absolute units were laid out today with our present knowledge of science the system would be devised without any such arbitrarily assumed accidental constants, which are not strictly constants at all. The c-g-s system is a purely terrestrial system and depends inherently on the constants of this terrestrial world and of a chemical composition H_2O which has obviously been chosen because it happens to be easily obtainable on our earth. The system stands and falls with the present conditions of the earth. It is not even purely decimal as the unit of time, at least, is arrived at after the manner devised by the Babylonians according to the duodecimal and sexagesimal system.

A real absolute unit system which is based on the fundamental properties of the universe, as we know them, might be the following: The first unit is not the unit of length or of time, but the unit of velocity which is a certain decimal fraction (arithmetically) of the velocity of light in empty space, for instance $1/10^8$, which would be roughly 3 m. or 10 feet per second.

The next unit would be the unit of mass which with our present knowledge we can choose without any reference to arbitrarily selected chemical compounds. We might for example choose as unit the mass of an electron or of the hydrogen atom (multiplied by a convenient integral power of 10)

These two units, the unit of velocity and the unit of mass, are then based on fundamental properties of the universe, as we know them, without any reference to accidental constants, such as the circumference of the equator of the earth, etc. Whereas in our existing absolute metric system we have three basic units, the centimeter, the gram and the second, from which all others are derived, we have in the velocity-mass system, just being explained, only those two fundamental units, velocity and mass, and all others, including length and time, can be derived from these. This fits in with the modern theory that mass (matter) is nothing but a form of energy.

The derivation of the other units from the two fundamental ones might, for instance, be done in the following manner: Two masses, each of unit size and each concentrated in one point, without initial velocity relative to one another, will fall straight towards one another in consequence of their mutual gravitation. They will meet in the middle of the straight line connecting their original positions, with a certain velocity which depends on their original mutual distance. If this distance is chosen so that the velocity of their collision is unit velocity, then that distance may be called the unit of length; and the time which is necessary for a body to travel at unit velocity through unit distance would be unit time. Or the time which the two bodies of unit mass require until they collide might be called unit time and the unit of length would be tied thereto by means of the given unit of velocity. Or we might imagine two bodies of unit mass revolving in circular orbits around their common center of gravity with unit velocity, having such a distance from one another that the centrifugal force just counterbalances the mutual gravitational attraction. This distance might then be the unit of length, the unit of time being again connected to it by means of the established unit of velocity. From the units of length, time, and mass all other units could be derived in exactly the same manner as in our present c-g-s system.

It is the privilege of an after-dinner dreamer to let his thoughts wander and we will now return from this little digression about what might be if events were different from what they have been.

We have determined the relations of length (space) and of time between the miniature earth and the real earth, and the question is as yet open: How shall the mass of everything be changed so that we get the same conditions on the miniature earth as on our original one?

Shall a body, for example a globe of cast iron, in being reduced in size, keep its density unchanged so that the mass reduces in the same measure as the volume, or shall the density be increased or reduced, in order to produce equal conditions on the reduced earth as on the original one?

Let us from now on—to get less unwieldy figures— assume the dimensions of the earth and of everything on it to be reduced in our model to 1/10 only, instead of as heretofore to 1/10,000. Then, as we have seen, time will also have to be reduced to 1/10; one second on the new system will be what is 1/10 second on our existing system; time will have to pass 10 times as fast, or else we will get a distorted model of the earth or rather of the space-time continuum, representing the earth and our whole universe.

All the following reasoning as well as the preceding applies as well to an increase in size as to a reduction. It must be understood that it is only for the sake of convenience of speech that a reduction has been assumed and that this reduction has been given the definite numerical value of 1/10. We might as well reduce to $1/n$ where n may be any positive real value.

We have seen that the velocities must remain unchanged, therefore a body falling to the surface of the earth must have the same velocity after the first second (or any other particle of time) on our earth and on the fictitious model of the earth. Or, it must have the same velocity after falling one foot deep on our earth as it has after falling one miniature foot on the miniature earth and the same applies to a fall over any given number of feet. The gravitational force pulling the earth and the respective falling body towards one another is proportional to the product of the two masses (earth and body respectively) and inversely proportional to the square of the distance between their respective centers of gravity. The acceleration of a falling body is proportional to the quotient of the force divided by the mass of the falling body, that is, from the above, it is proportional to the mass of the earth divided by the square of its radius. The velocity is proportional to the product of the time multiplied by the acceleration, that is proportional to the time multiplied by the mass of the earth divided by the square of the radius of the earth. The assumed reduction in size of the earth and everything on it to 1/10 of its original linear dimension reduces the square of the radius to 1/100 and the time must be reduced, as shown above, to 1/10 of its original value. Therefore, if the velocity as given above is to remain unchanged, we must reduce the mass of the earth to 1/10 of its original value. In a similar manner it can be shown that the mass of everything on the earth must also be reduced in the ratio 1:10.

The volume of everything on our earth will be reduced to 1/1000—seen from our actual existing universe—and the mass will be reduced only 1/10, therefore the density of everything will be increased 100 fold—as seen from our existing universe. Seen from the reduced time—space continuum—the density of everything is the same as on our existing one seen from the latter.

We see thus that not only all space dimensions but time and mass as well must be reduced in the same ratio, With uniform reduction of these five dimensions (using this term here rather loosely for lack of a better one), instead of the three space-dimensions only, to 1/10 of their original values, let us now check how various phenomena would manifest themselves in the miniature world.

The force of mutual gravitational attraction between two bodies would remain unchanged, as we have seen. Dividing this force by the mass of one of these two bodies gives us the acceleration of that body under the gravitational force and as the mass is reduced 10 times it appears that the gravitational acceleration would be enlarged ten times. This is, however, only an apparent deviation of the general uniform reduction and it is comparable to the reduction of the area to 1/100, or of the volume to 1/1000 discussed above as an example. The velocity of a freely falling body will be the same number of feet per second after the first second in the miniature world as it is in our original world;

it will be the same in both worlds after the next second of time and after the third, etc. The energy stored in the body by virtue of the velocity acquired will be the same number of foot pounds, etc. The length of a pendulum with a period of t seconds—given by $\frac{t^2}{\pi^2}g$ would be $\frac{1}{100}.10 = \frac{1}{10}$ times as long in the reduced system as in the original world, that is, it would be reduced in the same ratio as all other lengths. Centrifugal force would now also be unchanged.

Every body and every particle of every body must have 1/10 of the mass in the miniature world as the corresponding particle in the original existing world. Carrying the division into particles further and further we come to the conclusion that every molecule, every atom, every electron has only one tenth of its original mass.

Disregarding for the moment the question whether we can imagine an electron smaller—or larger—than what it really is, without coming into conflict with the present views of science, it can be easily shown that this reduction in mass in connection with the corresponding reduction of space and time dimensions will result in unchanged conditions of mechanical strength in the imagined miniature universe.

To take our former simple example: A large ball of, let us say, lead is suspended by a wire. Reducing everything, space, time and matter, to one tenth, as explained, will result in the same weight (gravitational pull) of the ball. The cross section of the wire is, however, only 1/100 of what it was before, so that the tensile strain in pounds per square inch measured in original pounds and inches will become 100 times as great. Each molecule in the wire has, however, 1/10 of its original mass whereas the number of molecules in the wire remains unchanged. Consequently the molecules are much closer together after the reduction of the dimensions: the mutual distance of any two molecules from one another will be reduced to one tenth of its former value. The mutual attraction of any two molecules will therefore be 1/100 : 1/100 of the original value, at least under the assumption that the attraction of the molecules follows Newton's law of gravitation as the larger bodies. The attraction between any two molecules remains therefore unchanged and therefore the resultant of this attraction between all molecules, which constitutes the mechanical strength, will remain unchanged. The reduced wire will have the same tensile strength after the reduction of all dimensions and as we have seen that the weight of the lead ball is also unchanged we arrive at the conclusion that although the tensile stress per square inch is numerically increased, still the safety coefficient is unchanged, after everything has been reduced to 1/10 of its original size. The same reasoning might, of course, also be applied to other kinds of mechanical stress, such as bending stress and to numerous other phenomena. For example, it can be easily shown that the height of the atmosphere necessary to produce the same pressure will now also be reduced to 1/10 of its original height, that is, it will have the same ratio to the diameter of the earth as before which, as we have found above, does not hold if we reduce the space dimensions only.

Now we can understand the deeper reason why the reduction of the space dimensions alone must of necessity result in a distortion of the imagined reduced model of the universe, a fact which amongst others expresses itself in a change of the mechanical strength of a given construction. Whether the imagination of a world reduced uniformly and equally in space, time and matter is reconcilable with our present views of physics is a question by itself, but a reduction of the space dimensions alone is not the uniform and proportional reduction which it seems to be at first sight. It is comparable, for instance, to a reduction of all dimensions perpendicular to the axis of the earth, leaving those parallel to the axis unchanged. Obviously the earth reduced in this manner would be distorted and likewise a reduction of the space dimensions only, leaving out time and matter, will also result in a distorted model.

To summarize: The reason why a uniform reduction of the size of every object surrounding us, including ourselves, will bring about a number of changes in the relations of these objects, for example in their mechanical strength, is twofold: There is established an absolute size in the size of the electrons, atoms and molecules, which is not affected by a simple change of size as long as the properties of the material remain the same. Moreover, there is established an absolute standard of velocity in the velocity of light, with the result that the time-dimension would have to be included in the reduction and changed in the same ratio as the three space-dimensions.

The Margins of Possible Improvement in the Central Station Steam Plant

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Truly a stupendous amount of human energy has been expended in improving the process of converting fuel energy into mechanical and electrical energy. The intricacy of the problem as a whole naturally led to the task being subdivided and to the separate steps of the process becoming the especial subjects for study, invention and refinement by separate groups of engineers. Great progress has been achieved, yet in such a method of development there is always the danger of losing a correct perspective of the ensemble endeavor. Consequently, it is of value to check up occasionally by reverting to a consideration of the fundamental principles underlying the whole proposition. The following article was written for this purpose. It presents an especially lucid analysis of the maximum theoretical efficiency of the ideal heat engine and then discusses the various physical limitations and margins of possible attainment. This paper was read before the American Society ot Mechanical Engineers at the annual meeting December, 1923.—EDITOR.

Many influences are tending to force manufacturers of power to use the greatest care in the layout of their plants in order to obtain the best possible economy of operation. The greatly diversified inventions requiring the use of electricity have much increased the demand for it. Existing plants are more and more pressed to the limit of their capacities and must get the largest output from the available equipment. Increasing costs of coal continually tend to emphasize the importance of the fuel charge in the total costs of operation, and point to the necessity of greater economy in its use. And a sentiment is growing more and more manifest that a high public spirit and the interests of the community require an economical use of natural resources.

It is appropriate, therefore, to take stock of the processes and methods available for improving steam-plant efficiency. The engineering periodicals exhibit a great interest in these questions and a large variety of improvements have been suggested. Usually the authors have devoted themselves to the careful and ingenious application of one or several methods of improving efficiency and have worked out the practical application of their ideas in particular cases. The purpose of the present article is to run over the whole field in a very general way, and to point out the limiting efficiencies attainable and show the lines along which the greatest margins for possible improvement lie. At the outset, then, practical and mechanical limitations will be disregarded in order to go first to the theoretically best economy. Fortunately this may be done in plain engineering language without the use of complicated mathematics. When this has been done it will be appropriate to discuss briefly the various difficulties in the way of going to the limit at once. Such speculations bring up very interesting problems in thermodynamical mathematics, which have, nevertheless, been avoided as far as possible.

In the case of any particular installation the correct procedure would, of course, be to start with good practice and make such improvements as can be shown to be desirable. The object of the present article will have been accomplished if, starting from the more remote ideal, it directs attention to the whole field open for selection and thus enables a more valuable choice to be made as to the best line of development to apply in a particular case.

The Ideal Conversion of Heat Energy

Fundamentally conceived, the steam plant is simply a heat engine for converting fuel into salable power. The textbooks outline certain theoretical facts about heat engines which it is convenient to recall at this time. A heat engine receives heat from a hot source, does work, and rejects heat to a cold receiver. The process of combustion may be considered as the hot source and the condenser as the cold receiver. Heat is directly convertible into other forms of energy at a fixed theoretical rate known as the mechanical equivalent of heat or the heat equivalent of electric energy. If the ideal heat engine could convert all of the heat into work at this rate it would be necessary to reject the working substance devoid of all heat content, that is, at absolute zero. A working substance to carry the heat is of course essential. If, at any time, energy is reclaimed from the working substance, without other heat exchange, its availability to do work has been decreased a corresponding amount, that is, its absolute temperature has been changed. In fact, this idea is the whole basis of the definition of the thermodynamic scale of temperature. Since the temperature of a condenser can hardly be lowered to absolute zero, it is necessary for heat engines in general to do work, even under ideal circumstances, at an efficiency far less than unity. This efficiency is represented by the actual temperature drop of the working substance divided by what the drop might be if all heat were abstracted, that is, the initial absolute temperature. This is the well-known Carnot-cycle efficiency and also the efficiency of any reversible engine.

As this idea of a reversible engine will come up again, it is well to recall it a little more carefully. It really must be the ideal engine because, if any other engine which might be thought more efficient—so that for a fixed amount of work done it has a smaller heat turnover—were used to drive the less efficient reversible engine as a heat pump, such a supposition would enable two isolated machines working together to have a net turnover of heat from a cold to a hot source. Such a condition is contrary to all experience, and the reversible engine with the Carnot efficiency is thus vindicated as the ideal engine. Furthermore, the textbooks go on to show not only that the Carnot efficiency cannot be exceeded, but that any cycle including an irreversible process is necessarily less efficient. An illustration may help to recall this point.

The transfer of heat from a furnace at 2000 deg. Fahr. to a boiler at 400 deg. Fahr. is an irreversible process. Heat cannot be caused to flow by itself from the boiler to the hotter furnace. As a result of the decrease in temperature the availability of the heat energy in the steam at boiler temperature to do work is very much less than the theoretical availability of the same amount of heat energy in the furnace at the temperature of combustion. On the other hand, if the boiler absorbed the heat of the furnace at furnace temperature, such a process would be reversible, and would enable the steam to work with the higher thermodynamic efficiency which the high temperature would permit. In fact, the idea of availability to do work is synonymous with thermodynamic efficiency, and this idea of loss of availability or thermodynamic efficiency in connection with the irreversible step is the important thing to note at this time. Hence it is well to recall the various types of reversible process.

The Carnot cycle is made up of an isothermal expansion and an adiabatic expansion, followed by an isothermal compression and an adiabatic compression. The isothermal process or heat exchange without alteration of temperature can, of course, be worked either way since no temperature drop is involved. The adiabatic process is reversible because it simply means no heat exchange to the outside at all but simply a conversion of internal or heat energy into external or work energy. Ideally, the isothermal is infinitely slow and the adiabatic is correspondingly sudden in order to be reversible.

There is also the regenerative process in which all heat that passes out of the working substance during cooling is transferred at its own temperature to an auxiliary contraflow substance, so that it may be restored at its own temperature during a similar return process. This requires the infinite slowness of the isothermal and the supposition of a perfect contraflow heater always in contact with the working substance, so that the temperature differences between the working substance and the auxiliary substance are always infinitesimal.

Temperature Limits

Certain very elementary conclusions are possible at once from this review of simple thermodynamic principles. It is desirable to have as cold a receiver as possible, and since there are practical limits to this coldness, it is also desirable to have the source of heat at as high a temperature as possible in order to give the widest possible operating range. These are the things that must be kept in mind when deciding on the efficiency of the ideal process.

With steam as a working substance and modern turbine construction it has been found that vacuums corresponding to temperatures between 70 deg. and 80 deg. Fahr. are the best that can be obtained with the cooling water available. Of course, it is imaginable that during an Alaskan winter a turbine might be made to exhaust into an air-cooled condenser at a temperature well below 0 deg. Fahr. Obviously in such a case the suitability of steam as a working substance would have to be considered in addition to the mere degree of coldness available.

Likewise, at the other end of the process it happens to be far easier to produce high temperatures than to utilize their advantage, because, in the case of steam, the vaporization at a high temperature cannot be accomplished without confinement at an excessive pressure. Thus it is evident that the working temperature range is hedged around by various practical considerations which will need special consideration, and this will be given presently.

The Thermal Processes

It is next important to consider the thermal processes and how closely they may be made to correspond with the ideal arrangement, that is, what sort of cycles can be used to the best advantage. It has been pointed out that the thermal processes should be either isothermal, adiabatic, or regenerative, that is, in every case reversible. Beginning at the furnace, the fuel and air are brought together in the presence of heat. Combustion takes place and more heat is liberated. This is absorbed by the boiler and carried to the engine by the working substance. Finally such heat as has not been converted into work is rejected to the condenser. But in addition the burned gases escape up the stack.

The Ideal Furnace

If, for the present, attention is confined to the furnace, it is plain that all the substance, fuel and air, which goes onto the grate and is heated must, in exactly the same quantity, disappear up the stack. Furthermore these substances which start at atmospheric temperature rise to the furnace temperature, and then are returned to the atmosphere, eventually cooling to their initial condition. Considering the approach to and exit from the furnace, it is plain that equal quantities of substance rise on the one hand and fall on the other through equal ranges of temperature. This suggests the recovery of all the waste heat of the flue gases by regenerative air preheaters. Ideally, these should be contraflow, with such surfaces and velocities that all the heat of the burned gases is transferred to the incoming air—and fuel also.

Next, considering the process of combustion, it may be regarded as a simple liberation of heat which occurs when the fuel and air are brought into contact at a high temperature. Suppose the fuel to be insulated from the air during preheating until the furnace temperature is reached, when combustion is permitted. Suppose the boiler to be so large that it will absorb the heat of combustion immediately without allowing any appreciable difference of temperature, the working substance being, in the ideal case, at the furnace temperature. This amounts to an isothermal transfer of heat and completes a reversible cycle in the furnace, at least from a thermodynamic point of view. The chemistry of combustion is another question. Still retaining the purely thermodynamic viewpoint, the furnace temperature is ideally arbitrary.

Furthermore, if the boiler is operated at a lower temperature than the furnace, the consequent loss of availability, according to the Carnot efficiency, must be charged against the boiler or its working substance and not against the furnace, since all the heat of combustion would still be transferred to the working substance. On the supposition of a perfect transfer of all the heat of the flue gases to the entering air and fuel, there would be no thermodynamic loss in the furnace, and if, in addition, an isothermal transfer of the heat of combustion to the boiler could occur, then the boiler could be included in the statement.

The Engine. Rankine Cycle not Ideal

Turning now to the working substance in the engine, the steam is the first consideration. It is not necessary to discuss the Rankine cycle for steam. Instead of the adiabatic compression of the Carnot cycle an increase of pressure at constant volume is used, a process which is not reversible. The thermodynamic efficiency has been calculated from the steam tables and plotted in Fig. 1 for dry saturated steam and for various initial temperatures and pressures. A glance at the diagram shows that the higher the temperature, that is, the higher the ideal efficiency, the farther does the Rankine cycle fall short of it.

This is especially true in the case of superheat, even though it improves the actual efficiency. The ideal efficiency rises enormously faster than the change in Rankine efficiency with superheat. With saturated steam the conversion from liquid to steam in the boiler, the expansion in the turbine, and the condensation are all reversible processes, only the process of heating the liquid being irreversible. On the other hand, with superheated steam the absorption of heat is no longer isothermal, so that in this case two out of the four processes which go to make up the cycle are irreversible. Hence it is reasonable that the latter cycle should fall farther below the ideal. Moreover it follows that for any particular temperature the less the superheat the higher will be the efficiency. In fact, for a particular temperature the efficiency is far the best if the pressure is high enough for the steam to be saturated.

The Extraction Cycle

The question now arises as to what cycle can be used in order to cause the steam to turn over the heat in accordance with the best theoretical standards. Obviously, the superheated-steam cycle is far from ideal. In fact, it is hard to justify the use of superheat from a purely theoretical viewpoint, although its application is thoroughly justified by a variety of practical reasons which will be discussed eventually. The Rankine cycle with saturated steam has only one process, the feed heating, which is not reversible. The idea of a regenerative process consists in many small exchanges of heat occurring at successively different temperatures in infinitesimal steps. Suppose the steam-extraction process be pushed to such a limit. It has been called a regenerative process, and this is true.

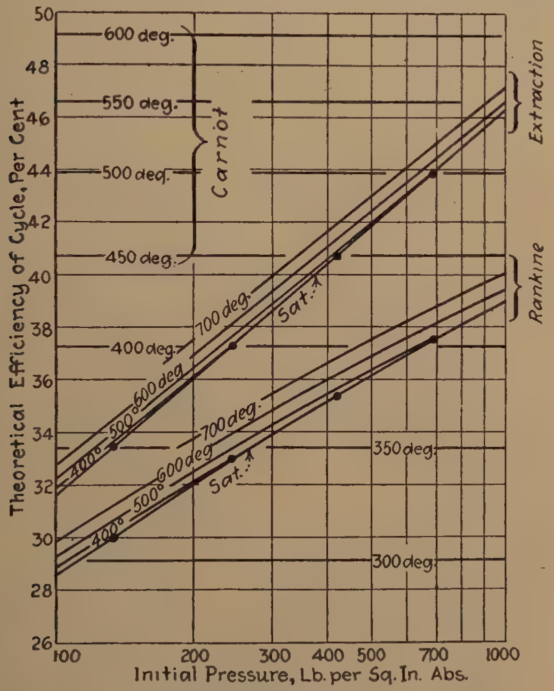

Fig. 1. Theoretical Efficiencies of Steam Cycles
(Based on Goodenough, 1917. Curves are for various initial total temperatures, deg. Fahr., as indicated. Back pressure, 1 in. Hg.)

Suppose steam is extracted from every stage of the turbine and that the number of stages is indefinitely increased. If at each stage just enough steam is extracted to heat the feed the infinitesimal temperature difference, each bit of steam so extracted has gone through a cycle reversible except for the infinitely small temperature drops during the feed heating, and these infinitesimal temperature drops occur in an unlimited number of small steps as in any regenerative process. The boiler temperature can thus be reached within an infinitesimal small amount. In other words, the extraction cycle as a whole is entirely reversible in the limit.

In order to understand clearly the truth of this statement, the reversed cycle is traced as follows: Starting with a hot liquid, it is caused by a very small cooling to evaporate a part of itself isothermally at a reduced pressure and that part is compressed adiabatically to the higher pressure and temperature in the boiler where it gives up its heat isothermally and condenses into the hot liquid. Further cooling will evaporate a further quantity at a still lower pressure, and so on. If done in a very large number of steps the process may be rendered as close as desired to truly reversible.

The steam-extraction cycle with saturated steam is thus, in the limit, a truly reversible process with the ideal efficiency of the Carnot cycle. Furthermore the demonstration has assumed only the pressure-temperature relation of a wet vapor. It is good not only for steam, but equally correct for saturated ammonia or saturated mercury. However, it does not apply to the case of a superheated vapor. This is an important fact to understand clearly. The equivalence of the Carnot and extraction cycles was demonstrated in the days of the steam engine before the common use of superheat, and as a result the literature is not clear that the inference is true only for wet vapors and not for superheat. Furthermore, it is easy to demonstrate this equivalence analytically on the basis of certain assumed algebraic relations of properties. Such demonstrations, using algebraic relations which are easily shown to be inexact, have failed to command confidence in the conclusion that the extraction cycle really is equal in the limit to the Carnot cycle.

This is about as far as abstract theory alone can go for the steam plant. The furnace and boiler have been imagined ideal by the use of regenerative air preheating with the flue gases, and the turbine has been imagined ideal by using saturated steam and heating the feed to boiler temperature by extraction. Thus the total margins for improvement are shown very clearly in Fig. 1, as explained before. The efficiency of the extraction cycle including superheat has been calculated according to the method outlined in the Appendix. It now becomes necessary to narrow the ideal still further by taking up the practical matters which determine the temperature limits and see what are the relative margins to gain among the various methods of increasing the efficiency. There are two principal questions: First, the temperature limits, and second, for established limits, how to approach as nearly as possible the ideal cycle.

The Upper Temperature Limit

The upper temperature limit is determined by the materials of construction rather than by the furnace or the working substance. Turbine materials maintain their strength, roughly speaking, up to 700 deg. Fahr. Turbine steels are usually good up to 800 deg. Fahr., but the gradient of decrease in strength per degree rise of temperature becomes so steep at higher temperatures that only very low stresses are allowable. Conservative practice therefore places 750 deg. Fahr. as the limit at the present time. It has been made clear that, unless saturated steam is used, the efficiency of the process will fall far below the ideal. And with saturated steam these temperatures are above the critical and the pressure above 3000 lb. per sq. in. Both the excessive pressure and excessive moisture during expansion make it undesirable to use saturated steam at such temperatures. The curves for the extraction cycle and the Rankine cycle in Fig. 1 show very plainly the magnitude of this restriction due to the pressure of steam at saturation temperatures. The horizontal lines indicate Carnot efficiencies, and it should be noted that extraction efficiencies and Carnot efficiencies for particular temperatures become equal at the saturation line.

The temperature-entropy diagram is useful for visualizing the differences in the processes. Fig. 2 shows the Rankine cycle *ABCD*. The heat put in is represented by the area *FABCDE* and the heat exhausted by the area *ADEF*. The Carnot cycle working between the same temperature limits has an efficiency which might be represented by certain areas constructed by drawing the lines *AG* and *GB*. For the same heat exhausted as in the Rankine cycle, the Carnot cycle would have to absorb heat *FGCE* and deliver work *AGCD*. It is plain, therefore, since the extraction cycle is equal in efficiency to the Carnot cycle, that it is represented by these areas, although only as areas, because the broken lines do not represent properties of the substance. Now with the superheated Rankine cycle the work area *DCHK* is added out of a heat addition of *ECHM*. The efficiency is raised because the added work area is a larger ratio of the added heat area than the original efficiency. But the work area of the Carnot cycle for the elevated temperature is represented by the area *APHK*, so that the small addition *DCHK* is a ridiculously unsatisfactory approach. Moreover the constant pressure line *BCH* is no longer isothermal. It is still possible to extract steam and heat the feedwater to the boiler temperature so that the efficiency may be made equal to and even slightly better than the Carnot efficiency for the saturation temperature *GBC*, but the feedwater connot be heated to the upper temperature limit without encountering the excessive pressures already mentioned. Hence this large area between the saturation temperature and the upper temperature accounts for the failure of the superheat cycle to meet the requirements of an efficiency corresponding to its temperature.

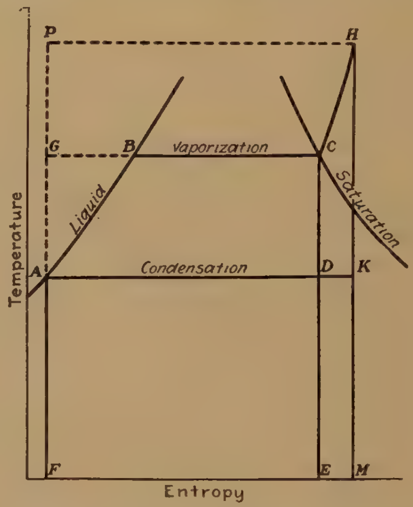

Fig. 2. Temperature-Entropy Diagram for Rankine Cycle with Superheating

The Advantage of High Pressure

It should now be clear why there is a theoretical advantage in the use of high pressures, even though the temperature after superheating is already at the limit fixed by the materials. In order to get the thermodynamic advantage of the highest temperature reached the steam must be generated at that temperature, a process which is practicable only for wet steam and provided that the required pressure is maintained. Thus it is clear that, due to the nature of a vapor, the pressure is quite as important as the temperature. The curves of Fig. 1 set forth the very material rise in theoretical efficiency with increase of pressure at various initial total temperatures, and it should be noted that the increase is still more rapid when steam extraction is employed. These curves have been carried to 1000 lb. per sq. in. absolute pressure. The manner of plotting on a logarithmic base renders the line so nearly straight that extrapolation is easy although it may not be warranted. Even at 1000 lb. per sq. in. the properties of steam are not known with precision. The pressure-temperature relation is, however, well defined and this shows that with saturated steam at 1000 lb. per sq. in. absolute pressure, using the extraction cycle, the efficiency, high as it is, only equals the Carnot efficiency for 542 deg. Fahr. and the temperature at the critical pressure itself is only about 700 deg. Fahr.

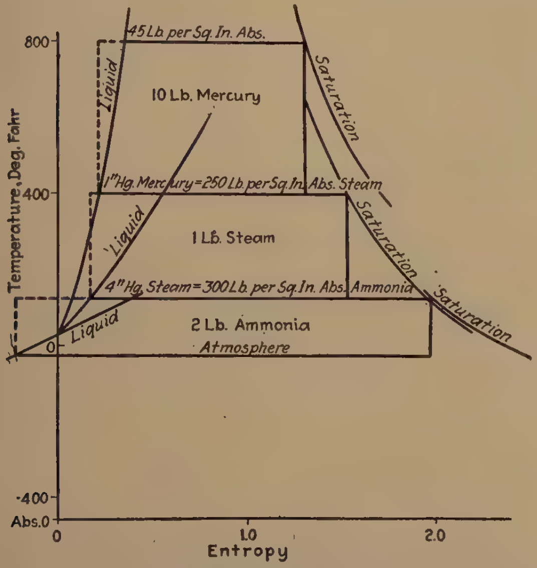

Fig. 3. Temperature-Entropy Diagram for a Combination of Mercury, Steam and Ammonia

The Binary-Vapor Turbine

The foregoing all points to the necessity of a substance whose vapor pressure will not be excessive at the temperature to which the materials of construction may be submitted. And this is the great advantage of the mercury turbine. Fig. 3 presents a temperature-entropy diagram for one pound of steam with a similar diagram for ten pounds of mercury drawn at the higher temperatures. In a particular machine the relative amounts of steam and mercury would be slightly different, depending on the temperature of the condenser-boiler. The ten-to-one ratio is convenient for plotting. The low pressure of 45 lb. per sq. in. at 800 deg. Fahr. is very satisfactory and the exhaust at one inch of mercury back pressure heats a steam boiler at 400 deg. Fahr. and 250 lb. per sq. in. pressure, the steam from which may in turn be expanded to one inch of mercury back pressure. The entire working range of temperatures is from 800 deg. to 80 deg. Fahr., and in each case wet vapors are used. In each case, also, extraction may, imaginably at least, be employed, although the mercury has so little liquid heat, as a glance at Fig. 3 shows, that its Rankine cycle is considerably nearer to ideal than is the case with steam. However, considering the ideal case, a simple scaling from Fig. 1 shows a theoretical increase of economy of the process just described of 37 per cent, as compared with good modern turbine practice using steam at 350 lb. per. sq. in. pressure and 700 deg. Fahr. temperature, and a saving of 28.7 per cent as compared with the same turbine utilizing the extraction cycle to the limit.

The mercury turbine has thus given a practicable way to reach the upper temperature limit as fixed by the strength of materials. The aim in that direction is now being directed at the materials of construction, and this is entirely correct.

The Lower Temperature Limit

At the other end of the process, the condenser, the temperature limit is fixed by natural conditions. Cooling water sufficient to maintain a vacuum at 80 deg. Fahr. is about as good as can usually be expected. However, it is the intention of this article to look somewhat beyond immediate possibilities in a variety of directions. Fig. 3 also includes the liquid and saturation lines for ammonia, and if a turbine were supposed to be equipped with an ammonia condenser-boiler, then another turbine, an ammonia turbine, might as easily continue the process as the steam turbine continued the mercury process. If such a steam plant were located in the polar regions in winter so that the atmosphere could condense the ammonia at −25 deg. Fahr., it would be possible to expand the ammonia to atmospheric pressure. Now if the feed is heated by extraction as in the case of the steam and mercury, the efficiency would be such as to effect a saving of 45 per cent over the case of a steam turbine working with the Rankine cycle at 350 lb. per sq. in. pressure and 700 deg. Fahr. temperature.

It may also be noted here that sulphur dioxide could be used with less severe pressures than ammonia. This might be a matter for consideration if the process were adopted, and there is another reason than the efficiency of the process for the use of a refrigerating fluid for the last few stages. The capacity of the compound unit, being dependent on the last wheel of the steam turbine, could be very much increased if the steam expansion were stopped at a moderate vacuum and the remaining energy utilized in one of the suggested refrigerating fluids which have very much smaller specific volumes at the temperatures in question.

The Advantage of Steam Extraction

Having thus discussed what the theoretical efficiency is and how various practical limitations determine what is ideal in any particular case, the next matter to consider is the utilitarian question of the value of the various improvements already instituted. The idea is to take up step by step various limitations that lie between the application of the perfectly general theory and present steam-plant methods. The advantage of the mercury turbine has been pointed out. The theoretical advantage of steam extraction is shown in Fig. 1. The practical advantage depends on the number of heaters. Very roughly it may be said that, in comparison with no feed heating, the use of one heater will realize between a third and a half of the full theoretical gain, and also, very roughly, that each additional heater will realize an improvement about half as large as the last preceding heater added to the system. It remains to discuss the advantage of or reason for superheating, resuperheating, drying, the economizer, air preheating, and the use of auxiliary feedwater heaters.

The Advantages of Superheat

The advantage of superheat, as mentioned before, is almost entirely a matter of practical application due to the limitation of a high initial pressure. The desired temperature cannot be attained with wet steam without incurring too high an initial pressure. Hence the pressure is pushed as high as possible and the slight advantage illustrated in Fig. 2 is realized by superheating. The theoretical value is plotted in Fig. 1 in terms of total temperatures. Fortunately, the use of superheat is attended with a non-thermodynamic improvement in efficiency which is roughly of the same order of magnitude as the theoretical improvement. This is attributed to removal of moisture in the lower stages of the turbine. And still further the greater heat turnover per pound of steam results in an even greater reduction of water rate, which is advantageous in permitting a larger capacity rating of the machine, as will be discussed in another place.

In order to visualize these advantages it may be said, very roughly, that the theoretical gain in economy is about 1.5 per cent for 100 deg. Fahr. superheat, while the non-thermodynamic gain is about as much more, making an overall reduction of heat rate in the neighborhood of 3 per cent per 100 deg. of superheat. The reduction in water rate is, on the other hand, of the order of 8 per cent per 100 deg. Fahr. However, this must be clearly distinguished from an increase in the economy of operation of the plant. A reduction of water rate does not mean a corresponding reduction in the fuel rate because reductions in water rate usually entail a substantial increase in the heat per pound absorbed by the steam in the boiler.

Resuperheating

The desirability of resuperheating is due largely to the same reasons that apply in the case of initial superheat. But the newness of the process makes it less easy to say what the gain may be beyond the theoretical amount. Fig. 4 shows at a glance that the cycle has been improved, roughly, by nearly the same degree as in the case of initial superheat as compared with saturated steam. The process is accompanied by a further reduction of water rate, as explained before, which is greater than corresponds with the reduction in heat rate. In passing it may be noted that this resuperheating process is a sort of partial expansion under isothermal conditions. For instance, if the resuperheating should take place in each stage, this isothermal expansion might go on to exhaust pressure. There would be a slight additional gain in economy, but the efficiency of the process would not approach the efficiency of the Carnot cycle. The possibilities of practical application to any particular advantage are limited to about one or two steps of resuperheating.

Drying

Drying may be accomplished by the same process as resuperheating, namely, by the addition of heat; but if the addition of heat is only sufficient to dry the steam without superheating it, the gain will be slight and due largely to increased mechanical efficiency in the process of energy conversion. On the other hand, if the drying is done by moisture abstraction, the gain is very appreciable. The moisture removed should be used for feedwater heating, and the practical rise of efficiency due to drier steam in the turbine should be realized. Here again it is impossible to say how much improvement can be realized until the method is put into practice. On the other hand, steam separators have been used for a long time, and the use of some form of separator in connection with extraction for feed heating would enable the removal of an especially wet sample of steam. In other words, instead of extracting a homogeneous sample, the extraction of all the moisture and only so much dry steam as might be required should enable one extraction drier used for feed heating to accomplish about as much gain in economy as, say, two extraction heaters of the surface-condenser type. This is a very rough statement and depends for its truth on the possibility of satisfactorily operating the drying process.

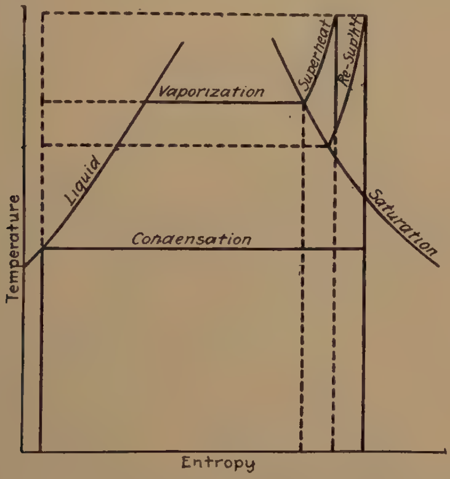

Fig. 4. Temperature-Entropy Diagram with Resuperheating

The Economizer

In all that has been said so far, there has appeared no place for an economizer. Indeed, as far as the theory goes, it appears to be anomalous. In considering the ideal furnace it was pointed out that flue-gas heat should be transferred to the entering air, and in considering the extraction cycle the logical source of feedwater heat was seen to be extracted steam. The economizer is intentionally aimed to extend the boiler process to a temperature below that corresponding to its pressure; i.e., to destroy its isothermal nature. But in all these cases where a substantial practice has grown up there is always a good common-sense reason sufficient to justify it at the time. Whether the practice should continue or not is always an appropriate question. The discharge of hot flue gas was a material waste. To pump cold water into a hot boiler was bad. And the transfer of heat from hot gas to water was a practical process well known, since it was taking place in every boiler; hence the economizer.

To secure an exchange of heat between large quantities of air with reasonable temperature differences is not so easy. The design of such apparatus is progressing at the present time, however, and installations of this nature have been made. It is certainly a process theoretically of such distinct value as to warrant serious attempts to accomplish its practical use. On the other hand, the success of this process will not in itself displace the economizer. The economizer works at temperatures roughly between 300 and 600 deg. Fahr., whereas grate manufacturers prefer the air to enter the furnace at a temperature less than 300 deg. Fahr. or certainly not much more. This is another very real limitation on the realization of the ideal arrangement. The inability to utilize this flow of fluid for returning low-grade heat to the furnace means definitely a corresponding amount of waste. Here is a very good reason for pulverized fuel, if it will permit the use of very hot air going to the fire.

Air Preheating from the Economizer

There are several alternative methods of connecting up these channels for the return of low-grade heat to the system. In examining them it should be kept in mind that the idea is always to have the heat transfer occur with the least possible temperature difference. That is, the process should be as nearly truly regenerative as possible.

One suggestion that has been made with a view to transferring the heat of the exhaust gases to the incoming air is to fill the economizer with an auxiliary hot-water heating system and pipe this to hot-water radiators in the inlet-air system. Such an arrangement would avoid the bulkiness of air-to-air heaters. The contraflow feature of a regenerative process might be utilized at each end. The water would have to be confined under a very considerable pressure in order to attain the necessary temperature. Such a system would, however, leave the feedwater free to absorb the heat of extracted steam, and perhaps a more suitable auxiliary liquid than water could be selected for the transfer of the heat of the flue gases to the air.

Air Preheating with Extracted Steam

The use of extracted steam for air preheating is another scheme. If the economizer is used at the same time, it will be observed that the recommended arrangements of the ideal process have been crossed. In detail, instead of recovering the low-grade heat by the two regenerative processes, flue gas to air and extracted steam to feedwater, the following processes have been substituted: Flue gas to feedwater and extracted steam to air. This is all right as far as it goes, but examination shows that the crisscross is not equivalent to the direct process. To make this plain it is noted that very roughly two pounds of air flow are required to one pound of water, whereas the specific heat of the air is only about one-quarter as much as that of the water. In the upshot, then, the air circulation can carry back only about half as much heat per degree rise as the water circulation. Moreover the limitation of grate temperature has been noted. It is thus evident that, even if all the air preheating should be done by extracted steam, it would still be desirable to extract more for feed heating.

Parallel Feed Heating

Still another arrangement occurs to the author. The economizer must receive reasonably cold water in order to work efficiently, whereas the extraction process is not pushed to its limit unless it heats the water to boiler temperature. Present arrangements send the feedwater from the heaters to the economizer, thus dividing the available temperature range between the two heating devices. A more efficient way than to divide the temperature rise would be to divide the circulation into two very roughly equal parts (supposing pulverized fuel and no limitation on the air-preheating temperature). One branch of the system would be sent to the economizer as it comes from the hotwell and should enable the cooling of the flue gases to a materially lower temperature than with feedwater already preheated. The other branch of the system should be arranged to receive extracted steam, including appropriate amounts from the high-pressure stages, since these temperatures no longer detract from the action of the economizer. Similar amounts of extracted steam would be used for preheating the air. Such a process in perfect adjustment would approach the ideal process.

The House Turbine

It is now time to discuss the use of a house turbine for feedwater heating. Very simply, if the house turbine has the same efficiency as the main units it is exactly equivalent to single-stage extraction. A house turbine is rarely as efficient as the main units, and generally means a less economical heat rate than extraction from the main units. On the other hand, it has certain advantages in the way of flexible adjustment that cause its use as a so-called "heat-balancer" element. By shifting the load on the house turbine the temperature of the feedwater may be regulated. It would be preferable to control the quantities extracted from the main units.

Steam Auxiliaries for Feed Heating

If steam auxiliaries are used for other reasons, the exhaust heat from these may be used for feedwater heating. It is interesting to read descriptions of this common practice which seem to reflect an opinion that it is desirable to create a number of losses in order to have losses to recover. Steam auxiliaries are usually very inefficient as compared with the main unit and therefore not to be compared with motor drive. In consequence the use of such heat is a waste as compared with extraction from the main unit. Furthermore, this heat is rarely added regeneratively but is dumped in at once, so that it reduces the ability to extract other steam more than in proportion to its own value.

The wisdom of having certain auxiliary drives duplicated by steam stand-bys in the interest of station reliability is not disputed at all. But it is maintained that the deliberate layout of a plant to heat the feedwater with such steam on the supposition that it is not lost is wrong because such a layout prevents the use of another arrangement which is more efficient. The heat returned to the system is not lost in itself, but for a given quantity of heat recirculated the auxiliaries can turn less into useful work than the main units. In other words, inefficient auxiliaries should not be placed in a station in order to provide feed heat which may be got from the more efficient main units.

Other Sources of Low-Grade Heat

There are also several other sources of low-grade heat about the station which may be used for feed-heating purposes. Among these may be listed the following possibilities: The exhaust from the turbine high-pressure packings; the heat of the steam air ejectors; the heat of the bearings as recovered from the oil coolers; the generator losses as recovered in the generator cooling-air circulation. In such cases it is perfectly plain that the loss should not be created in order to get the heat. But having the heat it is allowable to use it, especially if it does not hinder the use of other heat. In every case the process should be as nearly regenerative as possible, and the final test of usefulness is the effect on the heat rate of the station as a whole when compared with the effect of some other arrangement.

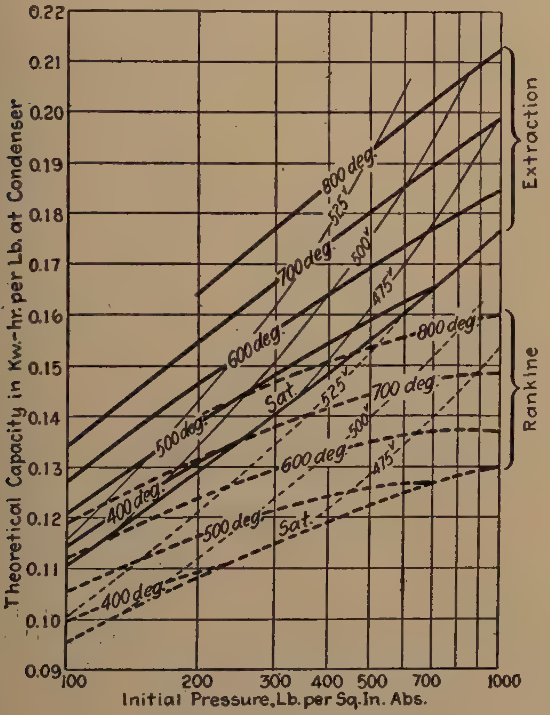

Fig. 5. Theoretical Capacities of Steam Cycles

(Curves are for various initial total temperatures in deg. Fahr. as indicated. Back pressure, 1 in. Hg. Fine lines show exhaust specific volumes in cu. ft. per lb. Based on Goodenough, 1917.)

The Final Criterion

The importance of considering the station heat rate as a whole is not always appreciated. As soon as the boiler plant and the turbine plant are connected by the regenerative processes the whole station becomes a single thermodynamic unit, and it is no longer possible to judge its economy by considering separately the boiler and the turbine. For example, the economizer may be made extremely efficient at the expense of all feed heating by extraction. Or the reverse may happen so that there is excessive waste in the flue gases. The only safe rule is to look at the heat rate of the whole plant. Furthermore, in accepting such a criterion the electrical apparatus must not be lost sight of, nor the fixed charges. No one would consider for a moment doubling the investment to obtain a one per cent increase in economy, and it is unwisdom of the same sort that focuses attention on any one element of the plant to the exclusion of its effect on the whole.

Capacity Rating

In conclusion, it seems necessary to consider the effect of the various improvements on the capacity of a unit. This relation has been noted repeatedly in passing, and it is a fortunate circumstance that improvements in efficiency usually result in a greater power output from a given amount of working substance and thus tend to increase the rated capacity of a machine. In the case of a particular turbine of large size, the rating depends on the volume of steam passing the last wheel so that reductions of water rate, especially water rate at the last wheel, cause corresponding increases in the rated capacity of the turbine. The reduction of water rate with superheat has been mentioned. A similar reduction occurs with increased pressure. The effect of steam extraction is obviously to reduce the water rate at the last wheel. Recent advances in the rating of single turbine units have brought the importance of this subject to the front, and it seems necessary to point out here the great increase in capacity which theory alone provides in the case of machines using the improvements which have been discussed.

Fig. 5 is a chart of reciprocal water rates or theoretical capacities in kilowatt-hours per pound of steam at the condenser. Curves have been plotted for the Rankine cycle with superheat and for the extraction cycle. Although the specific volume at the exhaust does not vary greatly, very fine lines have been added to show its theoretical value. A comparison with Fig. 1 shows at a glance how much more rapidly the capacity rises than the efficiency. For instance from 130 lb. per sq. in. absolute and saturated steam with the Rankine cycle to 750 lb. per sq. in. and 750 deg. Fahr. temperature with the extraction cycle, the capacity is just doubled while the economy is improved one-third. In this example the theoretically specific volume at the exhaust is the same in each case.

In the case of increased superheat at a fixed pressure the capacity rating of the machine increases less rapidly than the capacity per pound on account of the greater exhaust volume. On the other hand, with increased pressure at a constant superheat the capacity rating increases more rapidly than the capacity per pound because of the reduced exhaust volume. Generally speaking, increases of superheat have been accompanied by increases of pressure, so that exhaust specific volumes have been changed very little. It should therefore be plain that the continual increases of turbine rating which have occurred in the past decade without recourse to double-flow or multi-flow construction have been in a large degree due to true improvements in the thermodynamic processes. How much farther such improvements can be successfully carried is still to be seen.

The author wishes to acknowledge the valuable critical suggestions of friends who have read the manuscript of this article, especially Dr. B. L. Newkirk and Mr. G. B. Warren.

APPENDIX

The formulas for calculating the theoretical value of steam extraction as shown in Fig. 1 and Fig. 5 are given herewith. One pound of steam is supposed to go to the condenser. At any pressure during expansion the quantity of working steam is $(1 + w)$ lb. At this pressure the corresponding total heat is H and liquid heat is h. The subscript 1 indicates the initial pressure and 2 the exhaust pressure. The formulas are expressed in terms of liquid heat at any pressure. e is the base of the Napierian system of logarithms.

The heat balance for any particular infinitesimal heater gives the relation:

$$dw\ (H - h) = (1 + w)\ dh$$

Integrating, the amount of working substance is:

$$1 + w = e^{\left[\int_{h_2}^{h} \frac{dh}{H-h}\right]}$$

The energy E added to the Rankine cycle per pound of steam in the condenser, which is also the extra amount put in by the boiler per pound of steam in the condenser, is given by integrating the following expression for the work done by the steam going to any particular infinitesimal heater.

$$dE = (H_1 - H)\ dw = \frac{H_1 - H}{H - h}\ (1 + w)\ dh$$

$$E = \int_{h_2}^{h_1} \frac{H_1 - H}{H - h}(1 + w)\ dh$$

These formulas are used by tabulating or plotting the quantities as functions of the liquid heat. The integration is then performed graphically and the efficiencies and capacities are easily calculated.

Temperature Overload Relays

By B. W. Jones

Industrial Control Engineering Dept., General Electric Company

Overheating shortens the life of a motor and if extreme may cause an early burnout. Therefore some form of protective device is required. However, the device which is used to guard against overheating should function only when there is real danger. For example, damage might readily result from the application of an abnormal load to a motor that had about reached its maximum permissible temperature; but the same load might safely be applied to the same motor while it was relatively cool because of having run for some time under fractional load. To be ideal, the protective equipment should therefore take into account the immediately past history of the load. The following article describes two such devices.—Editor.

An electric motor consists of three kinds of materials: copper, insulation, and iron. The copper is heated by the current flowing through it. The insulation around the copper is a poor heat conductor but transfers the heat from the copper to the iron if the heat is not generated too fast in the copper. Thus, if a motor is carrying a small overload (125 per cent load) the heat has time to pass through the insulation into the iron, and the whole motor will increase slowly in temperature with the copper only slightly in the lead of the iron. This means that the effective thermal capacity of the motor for this kind of load is determined by the entire bulk of material in the motor which is relatively large, and therefore it will require a long time for the various parts to reach the rated temperatures.

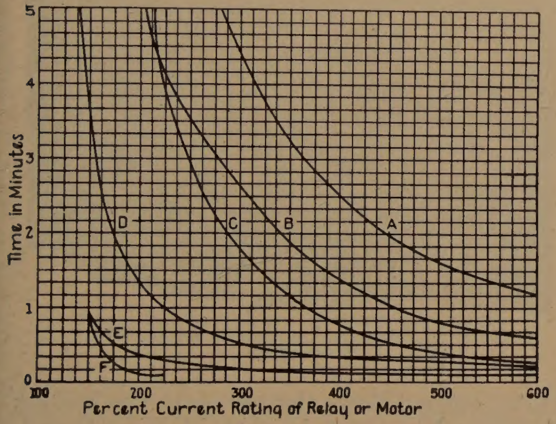

Fig. 1. Time-current Heating Curves

A: No. 4/0 B&S three-conductor cable
B: No. 2 B&S three-conductor cable
C: Two-element temperature overload relay or average size motor
D: Thermally lagged relay
E: Dashpot relay
F: 100-amp., 250-volt fuse

On the other hand, if the overload on the motor is large, such as a stalled squirrel-cage motor which will draw about six times its rated current, the heat generated in the copper will be thirty-six times normal, which is so fast in comparison to the rate at which the insulation can conduct heat into the iron that the cooling influence of the insulation and iron is negligible. Therefore the thermal capacity of the motor with this kind of load is determined entirely by the copper of the motor which is relatively small when compared to the remainder of the motor. This means that the characteristic heating curve of a motor is a composite of a large thermal capacity element for small overloads and of a small thermal capacity element for large overloads.

This feature is shown clearly in Fig. 1 which gives a typical motor characteristic heating curve and also some characteristic curves of cables suspended in air. The effective thermal capacity of a cable is a fixed amount for all loads. Different sizes of cables will have relatively different thermal capacities.

To fill the need for a motor protective device which operates on the principle of heat, the thermal overload relay was developed. When of the two-element type, this device furnishes adequate protection under all conditions and yet never takes the motor off the line before it is really necessary to do so. For example, a motor started cold can carry a given overload longer than can the same motor when previously heated under normal load; and, also, a motor can carry a certain overload longer in a given ambient temperature than the same motor in a higher ambient temperature. Obviously a motor protective device which takes these essential factors into consideration must be influenced by the previous load history and changes in ambient temperature. A temperature relay heated by the motor or line current inherently has these characteristics.

A second important feature which this thermal overload relay should have is a two-element thermal capacity characteristic so that it will duplicate the motor characteristic heating curve, which is a result of the influence of the insulation and iron on the copper. This is a very important consideration for a high-grade overload relay and any relay which has only a single element characteristic is an approximation to the required device.

A third important feature is that the overload relay should be adjustable relative to the current required to make it function but not adjustable relative to its thermal capacity. The relay should have a current adjustment so as to adjust the relay to its particular motor, but the thermal capacity of most average size motors is about the same and of course is built into the machine and cannot be changed. Therefore the corresponding feature of the overload relay should be built into the relay and not be adjustable.

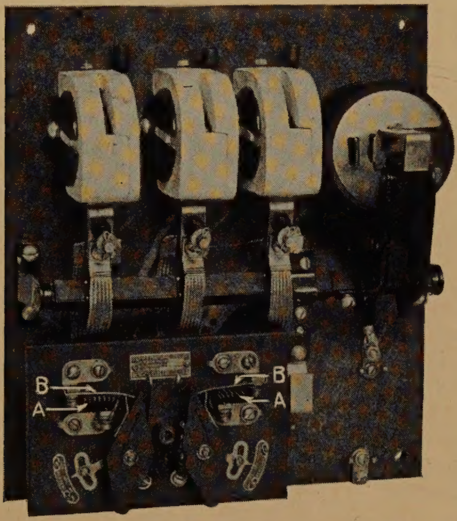

Fig. 2. Magnetic Switch Mechanism, Showing Two-pole Thermally Lagged Temperature Overload Relay

For the purpose of protecting all kinds of motors against overheating, two types of temperature overload relays have been developed. In this article, the first kind will be called a thermally lagged overload relay and the second kind a two-element temperature overload relay.

The characteristic heating curve of the thermally lagged relay approximately coincides with the characteristic heating curve of the motor at only one point; and this point has been selected at six times its current rating which is approximately the stalled current of a squirrel-cage induction motor. From this value towards the normal current rating of the motor, its characteristic curve falls well within the corresponding motor curve as shown in Fig. 1. This means that the relay provides safe protection to the motor at all loads, but at loads between 1¼ and 4 times normal the relay will take the motor off the line somewhat before it is necessary to do so. If the motor were carrying a widely fluctuating load this feature of the relay would show up. Comparing these curves, it will be noted that although this thermally lagged relay is not theoretically perfect, it is an advance over the previous types of overload relays.

Referring to Fig. 2, the construction of this thermally lagged relay will be seen. There are several forms of this type of relay. This one is for use with a multi-phase motor. The particular feature to be noted is that the motor current flows through only the heaters *A* (there being one in each of two phases). The thermostatic strip *B* acts as a latch and holds the control contacts together. The coils *A* heat the strips *B* by radiation, convection, and conduction, which results in a characteristic heating curve as shown in Fig. 1. The curve is seen to become quite flat at six times its rating, which means that at some high value such as 15 or 20 times its current rating the heater could fuse before it could deliver sufficient heat to the thermostatic strip to cause this thermal latch to trip.

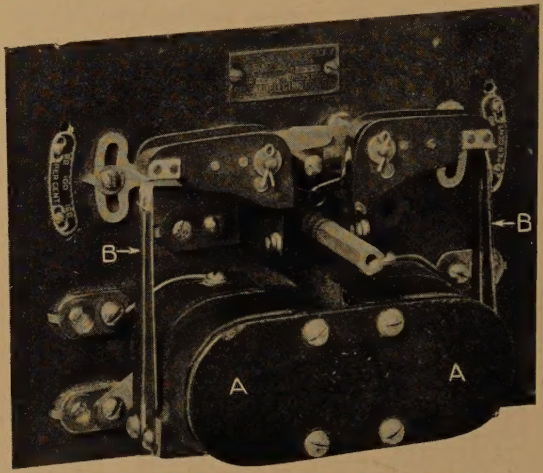

Fig. 3. Two-pole, Two-element Temperature Overload Relay

However, in fairness to this type of relay the following should be considered. There is a big demand for small, compact, enclosed starters to control small motors. These starters and motors are frequently connected to power lines which are fed by a large generating or transforming station. It is out of the question to endeavor to make these small starters open a short circuit on one of these lines. Fuses or their equivalent must be depended on to take care of other than normal operating conditions. Therefore if this thermally lagged relay is made small and of low cost, and gives full overload protection to the motor under normal conditions, it fills a very useful place in small compact starters.*

The second type of relay, which we will call a two-element temperature overload relay, is the highest grade temperature overload relay made. Its characteristic heating curve is the same as that of the motor under all kinds of loads. There is no exception to be taken because the relay has two elements which heat exactly as the copper and the iron of the motor. Referring to Fig. 3, the construction of this relay may be noted. The fundamental difference between this relay and the thermally lagged relay is that in this one the motor current flows through both the heaters *A* and the thermostatic strips *B*, and also the heaters *A* affect the thermostatic strip not by radiation and convection and conduction, as in the thermally lagged relay, but by conduction alone through a large volume of metal. For small overloads, the heater slowly raises the temperature of the thermostatic strip but in doing so it must heat a large volume of metal. Although the current flows through the thermostatic strip its I^2R loss is not large enough to affect it greatly. But since the heating in this thermostatic strip increases as the square of the current its I^2R loss begins to be the major effect when the current reaches three times or more of its normal rating. Thus, the metal block of the relay can represent the iron of the motor and the thermostatic strip can represent the copper of the motor. Therefore, for the small overloads the metal block provides the correct thermal capacity, and for the larger overloads the I^2R heating of the thermostatic strip gives the quick heating to the element which trips the latch, and this strip contains the same relative thermal capacity as the copper in the motor.

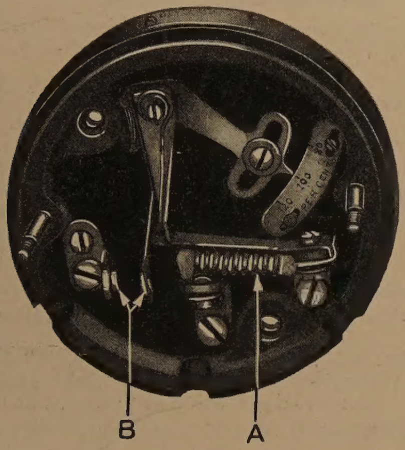

Fig. 4. Single-pole Hand Reset and Mechanically Operated Thermally Lagged Relay

A: Heater *B:* Relay contacts

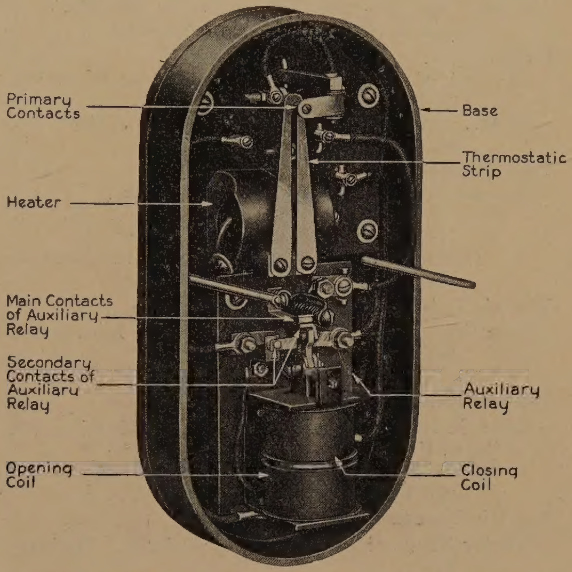

Fig. 5. Single-pole Electrically Reset and Electrically Operated Two-element Relay

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*The subject of protection against short circuits in contrast to protection against normal overloads is a very vital subject with which the writer will deal in a later article.

LIBRARY SECTION

Condensed references to some of the more important articles in the technical press, as selected by the G-E Main Library, will be listed in this section each month. New books of interest to the industry will also be listed. In special cases, where copy of an article is wanted which cannot be obtained through regular channels or local libraries, we will suggest other sources on application.

Alternators

Self-Exciting Alternators. Contell, F.
Elec. Rev., Feb., 8, 1924; v. 94, pp. 204-205.
(Short description of the principles.)

Balancing

Method of Balancing Turbine Rotors of Scout Cruiser *Raleigh*. Bean, Carlos.
Am. Soc. Nav. Engrs. Jour., Feb., 1924; v. 36, pp. 30-33.

Cars, Electric

Energy Consumption of Interurban Cars.
Elec. Rwy. Jour., Feb. 2, 1924; v. 63, pp. 171-173.
(An account of tests on cars of the Detroit United Railway.)

Electric Drive—Textile Mills

Selecting Motors for Cotton Mills. Maddocks, William S.
Elec. Wld., Feb. 9, 1924; v. 83, pp. 273-277.

Electric Heating, Industrial

Electric Industrial Heating. Drake, Hamlyn M.
Engr., Feb. 1, 1924; v.137, pp. 114-116.
(A discussion of results obtained in American practice.)

Electric Transmission

Power Transmission at Heavy Voltage. Hanker, F. C.
Elec. Lt. & Pr., Mar., 1924; v. 2, pp. 15-17, 52, 54, 56, 58.

Exciters

Excitation of Synchronous Machines. Jakeman, R. G.
Elec. Rev., Feb. 1, 1924; v. 94, pp. 167-168.
("The use of distributed exciting windings and uniformly-slotted exciting members.")

Furnaces, Boiler

Furnaces for Burning Small Sizes of Anthracite. Mumford, A. R.
Mech. Engng., Mar., 1924; v. 46, pp. 138-142.
(Their design as indicated by test results.)

Hydro-electric Development

Big Creek-San Joaquin Hydro-electric Project. Brown, Claude C.
Power Pl. Engng., Feb. 1, 1924; v. 28, pp. 167-172.
(Illustrated description of a Southern California Edison Company undertaking.)

Machinery—Inspection

Periodic Inspection, Cleaning and Testing of Alternating-Current Generators.
Elec. Wld., Feb. 9, 1924; v. 83, pp. 289-290.

Mercury Boilers

Binary Cycles Using Mercury and Steam. Greene, Jr., Arthur M.
Mech. Engng., Mar., 1924; v. 46, pp. 142-144.
(Short article on the theory).

Power Plants—Testing

Continuous Power-Plant Testing. Maynz, Theodore.
Power, Feb. 5, 1924; v. 59, pp. 205-208.
(Describes a method that permits boiler plant efficiency to be determined each day.)

Radio Communication

Wireless Communication with Lightships.
Engr., Feb. 1, 1924; v. 137, pp. 118-119.

Relays

Differentially Connected Relays for Protecting Electrical Machinery. King, C. M.
Power, Feb. 5, 1924; v. 59, pp. 210-211.

System Relay Committee. Crawford, M. T.
Elec. Wld., Mar. 1, 1924; v. 83, pp. 420-422.
(How the Puget Sound Power and Light Company formed a committee to improve service by a study of relay troubles.)

Substations, Automatic

Automatic Alternating-Current Substation. Schnell, C. E.
Elec. Wld., Feb. 9, 1924; v. 83, pp. 279-281.
(Describes a San Joaquin Light and Power Corporation station at Fresno, Cal.)

Vacuum Tubes

Three-Electrode Valve. Barrell, W. Sydney.
Wireless Wld. & Radio Rev., Feb. 6, 1924; v. 13, pp. 592-594.
(Elementary explanation of the operating principles. Serial.)

Water Purification

General Methods of Water Purification for Industrial Purposes. Heastie, B.
Engr., Feb. 29, 1924; v. 137, pp. 225-226.
(Abstract of a paper before a joint meeting of the Institution of Mechanical Engineers and the Society of Chemical Industry.)

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Electrical Insulation. Flight, W. S. 107 pp., 1923, N. Y., Isaac Pitman & Sons.

Financial Engineering. Ed. 2. Goldman, O. B. 325 pp., 1923, N. Y., John Wiley & Sons.

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Manufacture of Electric Steel. Sisco, Frank T. 304 pp., 1924, N. Y., McGraw-Hill Book Co., Inc.

Modern Electro-Plating. Hughes, W. E. 160 pp., 1923, Lond., Henry Frowde and Hodder & Stoughton.

Pulverised and Colloidal Fuel. Dunn, J. T. 197 pp., 1924, Lond., Ernest Benn.

Refractories for Electric Furnaces. Ed. 2. 96 pp., 1924, N. Y., American Electrochemical Society.